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VOLUME 27 SEPTEMBER 1960 No. 3

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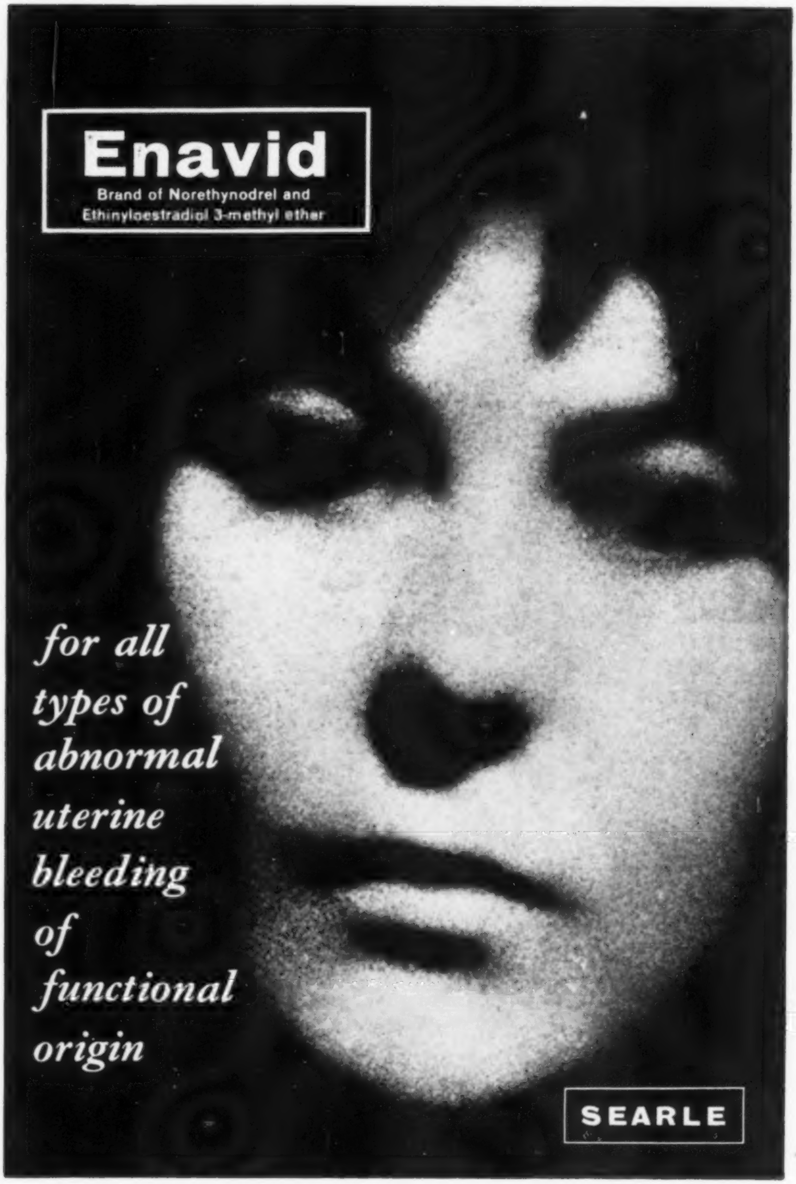
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TUMOURS OF CARTILAGINOUS ORIGIN

Moynihan Lecture delivered at the Royal College of Surgeons of England

on

11th February 1960

by

Bradley L. Coley, M.D., F.A.C.S.

Attending Surgeon Emeritus, Bone Tumor Service, Memorial Hospital, New York

It is, indeed, a great honour and privilege to be invited to give one of the lectures established in memory of Lord Moynihan and I should like to express my sincere appreciation to the Royal College of Surgeons for granting me this opportunity. It is a particular privilege when I recall the warm friendship that existed between Lord Moynihan and my father, and the gracious hospitality which both he and I enjoyed at Lord Moynihan's home in Leeds fifty years ago. The pleasure of this occasion is further enhanced by the recollection that my father also appeared before you in 1935 in what proved to be practically the last of his public appearances—the last, but undoubtedly the one that meant the most to him in his entire professional career.

In selecting a topic for this occasion, I am fully aware of the fact that the field in which my principal efforts have been directed is one that may not, perhaps, be of great interest to many of you. Nevertheless, I have chosen as my subject *tumours of cartilaginous origin* because I feel it is one that raises many questions and poses definite problems that should be of concern to those who are called upon to deal with diseases of the skeletal system.

Tumours derived from cartilage or containing cartilaginous elements may be divided into three groups: those that are apparently benign; those that are frankly malignant; and those that are originally benign but later became malignant.

Those of the second group that are malignant from the start we have termed *primary chondrosarcoma.* They are usually seen in children, in adolescents, and less often in young adults, and resemble osteosarcoma in that they are commonly encountered in the same age group, require the same treatment, and have the same unfavourable prognosis; however, they occur much less frequently than do the true osteosarcomas. Some of these primary chondrosarcomas assume a highly undifferentiated, anaplastic form and it may then be difficult or even impossible to differentiate them from anaplastic osteosarcoma. In the past, all chondrosarcomas were classified by some authorities as *osteogenic sarcoma* and it might be argued that primary chondrosarcomas should still be included in that category.

Our chief concern, however, lies in the benign cartilaginous lesions and particularly in their proclivity to undergo malignant transformation after long periods of quiescence and by insensible gradations. This change takes place insidiously and without any known precipitating factor. In order to qualify for consideration as a secondary chondrosarcoma a tumour must have presented, in the earlier phases, features that are characteristic of a benign neoplasm. These include long-known duration, and a characteristically benign roentgenographic appearance. Furthermore, they must eventually present clinical, roentgenographic, and histologic evidence of chondrosarcoma or they must ultimately metastasize and end fatally.

Fig. 1. (*a*) and (*b*) Secondary chondrosarcoma of femur arising on an osteochondroma. (*c*) Result after local resection. Patient well 23 years after operation.

This inherent tendency to malignant transformation is noted more frequently in benign tumours of cartilage origin than in any other benign lesion of the musculo-skeletal system; it may be compared to the proclivity of polyps of the large intestine to become carcinomatous.

There are a number of reasons why the medical profession in the past has been unaware of or not fully impressed by the possibility of secondary chondrosarcomatous degeneration on the part of benign cartilage lesions. The latter are encountered infrequently and some varieties may be said to be rare. It is extremely difficult to determine statistically what percentage of these lesions undergo malignant transformation, for many escape the attention of the medical profession until sarcomatous changes have already taken place.

The interval of time required for such evolution is unquestionably a long one. We have observed a number of cases where the interval between the discovery of the benign tumour and its recognition as a secondary chondrosarcoma was as long as from twenty to thirty years. Undoubtedly many are congenital aberrations. The comparative absence of symptoms and physical findings explains in part why they are not often discovered early or, if they are, why little attention is paid to them. By the time they come to a surgeon's attention they may already have become chondrosarcoma.

Pain is the most dependable early symptom of this serious transition, and we have learned never to ignore it. It is often mild at first, inconstant, and of gradual progression. When the tumour has become palpable any definite increase in size or change in shape is also an ominous sign.

Perhaps the most disturbing feature of the early, slowly growing, secondary chondrosarcoma is the difficulty of recognizing its malignant nature on the basis of biopsy material or even when the entire bulk of the tumour has been submitted to the pathologist. Every experienced pathologist with whom I have discussed this problem has freely recognized the difficulty and admitted that it may be quite impossible at times to render a positive histologic diagnosis in cases where the clinical and roentgenographic findings point unequivocally to chondrosarcoma. The problem will be further discussed later.

At this point it may be useful to present a simple classification of tumours derived wholly or in part from cartilage.

CARTILAGE TUMOURS

- Benign:
  - Osteochondroma (Osteocartilaginous Exostosis)
    - Solitary
    - Multiple (Hereditary)
  - Enchondroma
    - Solitary
    - Multiple
    - Multiple with Haemangioma (Maffucci's syndrome)
  - Juxtacortical Chondroma
  - Benign Chrondroblastoma (Codman's tumour)
  - Chondromyxoid Fibroma
- Malignant:
  - Chondrosaroma
    - Primary
    - Secondary
      - Central
      - Peripheral
      - Juxtacortical

Osteochondroma

Solitary osteochondroma is a benign lesion that projects from bone and may affect any bone which is preformed in cartilage. Much of its bulk is composed of bone, but it is always surmounted by a cap of cartilage. It has a predilection for long tubular bones, especially the femur, tibia,

humerus, and radius; but it is also found in the innominate bone, scapula and ribs. The roentgenographic appearance is so characteristic that a diagnosis by this means is readily made. Simple removal by resection of the entire growth including the base is adequate and is indicated if it is causing pressure symptoms, or showing increase in size, or for cosmetic reasons, or to prevent subsequent development of chondrosarcoma.

Multiple cartilaginous exostosis is an hereditary form which is not rare. Males are affected more often than females. The hereditary background has long been recognized. It has been stated that one-half of the offspring of an affected person will present evidence of the condition. The characteristic bony protrusions are most noticeable in the long bones, particularly

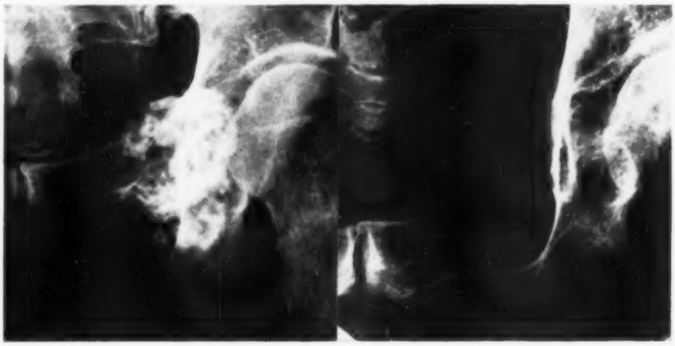

Fig. 2. (*a*) Secondary chondrosarcoma arising on one of a number of multiple (hereditary) osteocartilaginous exostoses. (*b*) Appearance following local resection. Patient well 3 years later.

in the region of the knee and ankle, and tend to a bilateral symmetrical distribution. They are usually discovered in early childhood, when the parents notice painless "bumps" attached to bone. Occasional cases escape detection until adult life, and unquestionably some may never be discovered clinically.

Both the solitary and the multiple osteocartilaginous exostoses may develop secondary chondrosarcoma, but in the former type such an event is infrequent as compared to the multiple variety.

Enchondroma

Central chondroma or enchondroma also occurs in solitary or multiple forms and affects the same bones as osteochondroma. In the long tubular bones it is not so frequently confined to the metaphysis. It may cause bulging of the bone, especially in the metacarpals and phalanges. The sexes are about equally affected.

Symptoms may be entirely absent, and when present are seldom pronounced. The condition often remains undiscovered until middle adult life and may be disclosed as a result of an X-ray examination made for some unrelated reason, or following a pathologic fracture, especially of a phalanx. Such fractures heal promptly with little or no deformity, and the chondroma may remain quiescent for many years thereafter. In most cases the malignant transformation of a solitary enchondroma is extremely slow in its development, but in exceptional cases its growth rate may be greatly accelerated.

Fig. 3. (*a*) Secondary chondrosarcoma of scapula arising on an enchondroma. (*b*) Appearance after total scapulectomy. Patient well 24 years after operation.

The multiple variety of enchondroma has been termed Ollier's disease or multiple enchondromatosis. In reality it is a cartilaginous dysplasia of bone, an anomaly of cartilage development. Several or many bones may be affected with a tendency toward unilateral distribution, such as one sees in cases of polyostotic fibrous dysplasia. Heredity is not considered to be a feature. The condition may produce visible and palpable swellings particularly in the bones of the hands and feet.

The source of cartilage in enchondromas has never been clearly established. Virchow (1875) conceived it as coming from the cartilage plate, while Speiser (1925) maintained that in some instances it originated from periosteum. The symptoms, as in other benign tumours of cartilage, are

mild and inconstant or entirely absent. Malignant changes are not infrequent in the solitary form, but are more common in the multiple variety where some authorities estimate an incidence of 50 per cent.

Once such changes have taken place, pain is complained of and becomes more constant and severe as the process extends. If untreated, the sarcoma tends to thin the cortex and eventually penetrates it to invade the adjacent soft parts, thus forming a sizeable tumour. The task of deciding from histologic evidence whether the process is a benign chondroma or a low-grade chondrosarcoma is a difficult one, and many pathologists tend to underdiagnose these lesions. In recent years, however, we have detected a growing appreciation of the criteria of increased cellularity, of more than an occasional binuclear cell, and of plumpness of the nuclei.

Before leaving the subject of enchondroma, a rare condition known as Maffucci's syndrome should be mentioned. This is a form of multiple enchondromatosis with associated multiple haemangioma of soft tissues. The haemangiomas are apparently a separate and unrelated anomaly of the vascular system which has been compared to the skin pigmentation seen in cases of polyostotic fibrous dysplasia. Jaffe (1960) has seen chondrosarcoma arise in cases of this disease, but it must be a rare finding, one that we have never observed.

Juxtacortical chondroma

The tumour which has been called periosteal chondroma (Lichtenstein and Hall, 1952) and juxtacortical chondroma (Jaffe, 1956) was first described in 1952. Its rarity is attested to by the fact that the combined experience of these two authors comprises less than two dozen cases. Clinically it presents as a small rounded swelling, of slow development, and of firm fixation to bone. Since the symptoms are negligible or absent and the mass usually inconspicuous, it may have been present for months or years before its presence is recognized. The mass is non-tender and may not increase in size for long periods. The roentgenographic findings may be quite inconspicuous and reveal only a soft tissue shadow contiguous with the cortex. There may be an underlying concavity with some marginal sclerosis, but the indentation does not extend through the entire cortex to invade the medullary cavity. The appearance may resemble that of a fibrous cortical defect or a giant cell tumour of tendon sheath origin which has indented bone.

Microscopic examination reveals lobules of hyaline cartilage whose cells lie in rather large lacunae, but cellular atypism and binuclear forms are lacking. Jaffe (1958) maintains that a fairly high degree of cellularity does not of itself indicate malignant tendencies—in which respect it differs from central cartilage lesions.

Conservative surgical removal has been successful in most of the reported cases and no instance of secondary chondrosarcoma has as yet been recorded; however, we have observed one case which we believe falls in this category.

Benign chondroblastoma

Thirty years ago Codman (1931) recognized the specific nature of this tumour, which he believed was peculiar to the proximal end of the humerus and to which he gave the name *epiphyseal chondromatous giant cell tumour*. Jaffe and Lichtenstein (1942), a decade later, pointed out that it bore no relation to giant cell tumour; they designated it as *benign chondroblastoma*, by which term it is generally known to-day.

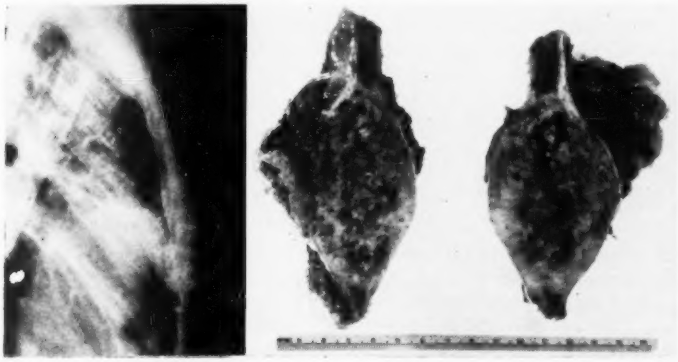

Fig. 4. (*a*) Secondary chondrosarcoma of sternum arising on longstanding enchondroma. (*b*) Gross specimen following resection. Patient died of disease within 2 years.

The majority of cases are recognized during the second decade of life. It is seldom seen below the age of 10 or past the age of 25 years. It is not confined to the proximal end of the humerus although this is the most favoured site. Other long bones, such as the femur and tibia, may be involved.

In common with other benign cartilage neoplasms, the symptoms are mild and often of long duration. They consist of slight pain and swelling with scant limitation of motion in the contiguous joint; tenderness of mild degree may be present. The roentgenographic features are those of a circumscribed lytic area which presents a fuzzy, mottled appearance due to irregular calcification within the tumour. The cortex may be expanded eccentrically, but not to a marked degree, and peripheral increased bone density is not unusual. The lesions with which it may be confused roentgenographically are: central chondrosarcoma and giant cell tumour.

Microscopic examination reveals polyhedral cells of moderate size which may be closely packed or with some intercellular substance. Spotty areas of focal necrosis and calcification together with zones of metaplasia into osseous tissue are characteristic features. The giant cell components are similar to but much less conspicuous than those seen in giant cell tumour and are found singly or in small numbers adjacent to the necrotic and calcified areas. There are no histologic features to suggest that the tumour is malignant. Jaffe (1958) believes this tumour to be derived from cartilage germ cells and to be distinct from the chondromyxoid fibroma. Stout (1960) concedes it to be a distinct neoplasm and not a chondrosarcoma, but he is not certain that Jaffe's explanation is correct.

The treatment should always be conservative; thorough curettage with bone-chip implantation has been consistently successful. We can find no record of chondrosarcoma arising on a benign chondroblastoma nor have we ever personally observed this complication. Hatcher and Campbell (1951) reported a case of benign chondroblastoma, however, which after roentgen therapy totalling 3,600 roentgens developed a chondrosarcoma which they believed was induced by the radiation.

Chondromyxoid fibroma

The specific benign tumour of bone known as chondromyxoid fibroma was first described by Jaffe and Lichtenstein in 1948. It is a rare tumour; the combined series of these authors totalled only about 55 cases. It is usually seen in older children and young adults. The sexes are about equally affected. The lower limb bones are the most frequent site, with the tibia predominating. In 1957 Iwata and Coley (1958) collected 36 cases from the literature, and found that in 32 cases the growths were located in the pelvis and lower extremity.

Mild pain of long duration is the usual complaint. Occasionally the lesion is discovered on roentgenographic examination made after some local injury. In two cases rib lesions were discovered after a routine chest X-ray examination. Roentgenographic findings reveal a metaphyseally located lesion of a long bone which is usually eccentrically placed but may involve the entire width of the bone. It appears as a round or oval radiolucent area which may expand and thin the overlying cortex. Encapsulation is the rule and may be by a rim of cortex or by periosteum. The depth of the tumour may be bordered by a zone of sclerotic bone.

This tumour may prove to be a difficult one to identify histologically. The microscopic picture differs in individual cases and in different areas in the same case according to the preponderance of either the chondroid or the myxoid components which comprise the lesion. Groups of cells are occasionally encountered which resemble benign chondroblastoma, but this should not lead one to assume that the two are morphologically

related. In the past, cases of chondromyxoid fibroma have unquestionably been mistaken by pathologists for chondrosarcoma and this error may still have to be considered. Jaffe (1958) appreciates these difficulties when he states: " Altogether, the chondromyxoid fibroma is the kind of lesion for whose proper identification one has to call upon a sort of sixth sense to amalgamate a number of minute evanescent impressions into a distinctive whole."

The treatment is surgical and should be conservative, consisting of curettage or, if practical, resection. During the ten-year period following the first description of the condition no cases of secondary chondrosarcoma had been reported; however, in 1958, Iwata and Coley recorded the first instance of such complication. The patient was a 17-year-old Panamanian male who, after two unsuccessful attempts at removal of the tumour from its site in the proximal fibula, was subjected to a segmental resection of the proximal third of the bone. Sections from the first and second operations were reported as showing chondromyxoid fibroma, but those from the segmental resection revealed low-grade chondrosarcoma. These findings were confirmed by Jaffe. Thereafter a prompt above-knee amputation was performed on 2nd April 1956; the patient recovered and has remained well and apparently free of disease up to the present time. We suspect that other such cases will be reported in the future.

Secondary chondrosarcoma

Having discussed the various benign tumours and their tendency to become malignant, it may be well to consider in some detail the secondary chondrosarcomas. Since the benign cartilage tumours are either central or peripheral in origin it is consistent to use a similar classification for the secondary chondrosarcomas.

Peripheral chondrosarcoma is seen more often in males than in females. In our experience the ratio in 25 cases was 16 to 9. The average age on admission was 36.5 as compared to 41 for the central variety. It has a predilection for the innominate bone, femur, and humerus. It may develop so gradually and present such mild symptoms as to permit it to reach considerable size before medical attention is sought. Local resection in selected cases is adequate but should encompass the tumour by a safe margin, but if local recurrence supervenes then further conservative surgery is seldom justified.

Secondary chondrosarcoma of central origin affects sexes about equally, viz. 15 males to 12 females in our series. It has a predilection for the proximal and distal metaphyses of the femur, although the humerus, tibia, and ilium are also frequent sites, as are the scapula and sternum. In short, the tubular bones are infrequently affected except in multiple enchondromatosis. The evolution of the sarcoma is a slow process, and recurrence

after incomplete operations, such as curettage, is the rule. There is a tendency on the part of each recurrence to appear more promptly, and for the histology to show progressive indications of malignancy. The size of the tumour and the fact that it has undergone recurrence should be given great weight when trying to interpret the microscopic picture. As Jaffe (1958) has so aptly stated: " Altogether, in evaluating a cartilage tumour which is suspected of being a chondrosarcoma whichever feature (pathologic or clinical) is the most sinister should be regarded as the most important." We have on many occasions disregarded the microscopic report of *chondroma* when the clinical features of pain and large size together with the roentgenographic appearance were not in keeping with a benign tumour, and have proceeded to perform radical surgery, including

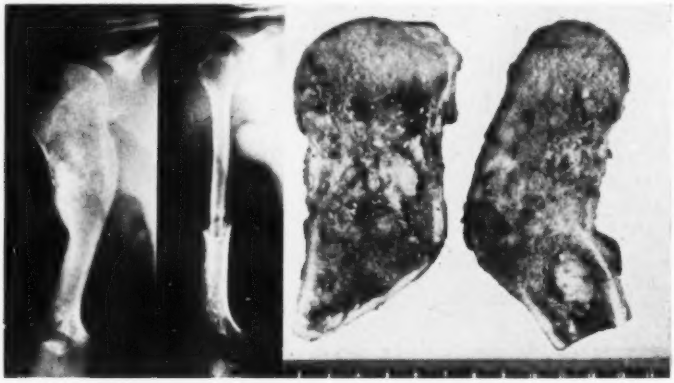

Fig. 5. (*a*) Secondary chondrosarcoma of humerus arising on an enchondroma of humerus known to have existed for 18 years. (*b*) Resection and implantation of proximal fibula. (*c*) Bisected gross specimen. Patient well 8 years with excellent function.

amputation. Thus far we have had no occasion to regret such action, since in each case we have eventually obtained microscopic proof or other confirmation of the malignancy of the tumour.

The roentgenographic findings are a valuable aid in making a correct appraisal. The most consistent feature is a spotty, irregular radiopacity which is due to calcific areas within the tumour, accompanied by irregular radiolucent areas which may give the appearance of loculation. Expansion of the cortex without break-through is a relatively early finding. Later there will be indications that the growth has erupted and a soft-part mass will be seen at the point of break-through. In some cases a central sarcoma will so weaken the bone as to produce a pathologic fracture and thus permit ready escape of the tumour into the soft parts where it forms a bulky swelling.

Unless the growth is completely inoperable the treatment of secondary chondrosarcoma is purely surgical, since in our experience radiation has not been successful in controlling the local lesion. The type of surgical procedure chosen should be one that is calculated to remove the tumour completely without encroaching on it at any stage of the operation. In the case of peripheral chondrosarcoma, that is more readily accomplished; but in the central variety the disease often extends beyond what appears to be its limits as visualized on X-ray films.

Curettage should not be employed for chondrosarcoma. Excision of a peripheral lesion including a broad base of normal bone is occasionally indicated, and we have one such example that has survived with unimpaired function for a period of 20 years. Wide resection is applicable to selected cases involving the iliac crest, sternum, ribs, and scapula, and, in certain conditions, one of the paired limb bones, e.g. proximal fibula.

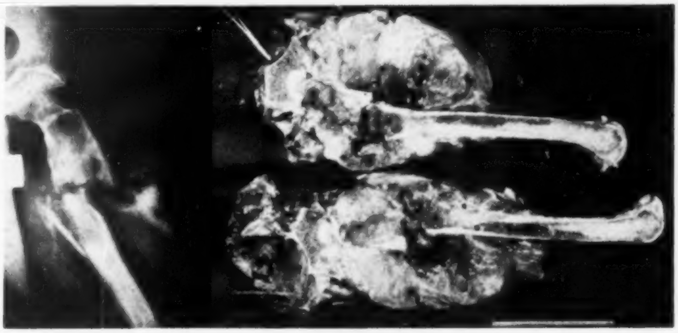

Fig. 6. (*a*) Secondary chondrosarcoma arising on enchondroma of femur. (*b*) Gross specimen following hemipelvectomy. Patient well 13 years later.

Central chondrosarcoma, for reasons mentioned above, demands more radical treatment. Infrequently one encounters cases where segmental resection with replacement by massive graft is the method of choice, but there is a risk that local recurrence will follow inadequate removal. Unquestionably, amputation is the safest procedure and should be carried out proximal to the involved bone. In low-grade secondary chondrosarcoma one can sometimes perform amputation successfully even after a segmental resection has been followed by a local recurrence; and in any circumstances it is justifiable to employ resection when the patient steadfastly refuses amputation.

Scapulectomy is worthy of serious consideration as a substitute for interscapulothoracic amputation when the growth does not impinge on the shoulder-joint, because it may provide assurance of as complete

removal as is obtained by the more radical operation, and will leave the patient with a serviceable upper extremity. One of our cases of total scapulectomy has survived almost 25 years and has retained singularly satisfactory function.

Amputation is, of course, indicated for the majority of chondrosarcomas of the tubular bones, either central or peripheral, and the more conservative operations that have just been enumerated should be reserved for exceptional and carefully selected cases.

Hemipelvectomy is the method of choice in dealing with low-grade chondrosarcoma in the neighbourhood of the hip-joint, including those

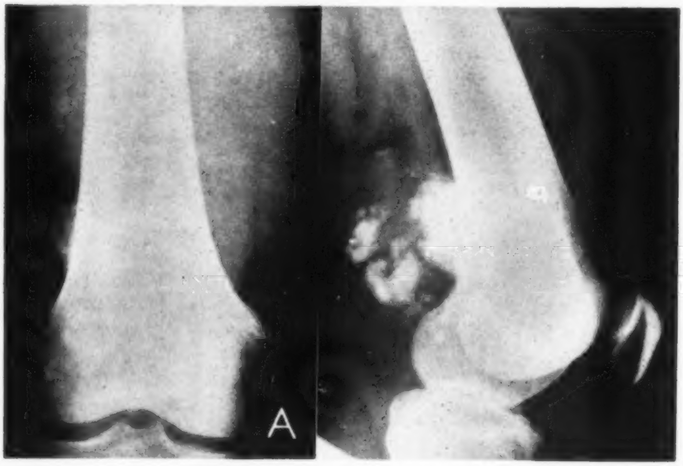

Fig. 7. (*a*) Juxtacortical (parosteal) chondroma. (*b*) Secondary chondrosarcoma developing after two unsuccessful local resections. Amputation was followed by death from a pulmonary metastases.

arising in the innominate bone. Our experience with this operation convinces us that it yields gratifying results and that this type of neoplasm offers the strongest indication for its use. We believe that more of our patients could have been saved if the decision to employ hemipelvectomy had not been deferred until irradiation or ineffectual local surgery had been attempted.

It is surprising how long an interval may occasionally elapse between amputation and death from metastases. In one of our cases it covered a period of 15 years, and in another almost 10 years. Metastasis to the lungs is the usual cause of death, although in three of our cases deposits in the heart were discovered at autopsy.

It has become increasingly apparent that a five-year follow-up is inadequate to determine the outcome in this disease, and a period of at least 10 years is recommended.

The prognosis for secondary chondrosarcoma could be improved if certain steps were observed: Patients with single or multiple bony protrusions should be cautioned to report at once any pain in the area or any change in the size or shape of the lesion; any patient who has had a benign cartilage tumour should have careful follow-up examinations in order to detect as early as possible any tendency to a superimposed chondrosarcoma; the medical profession should adopt a more aggressive attitude in handling patients with benign cartilage lesions and should appreciate the significance of pain, the fallibility of microscopic interpretation and the serious implication of local recurrences of a supposedly benign tumour; finally, the profession should be aware of the hopeful prognosis for long-term survival in cases that are treated early and adequately.

The comparative infrequency with which cartilage tumours are encountered in the average hospital prevents most surgeons from accumulating sufficient experience to interpret the findings, and to select and carry out the ideal method of treatment in an individual case. Special clinics for bone tumours would provide the necessary volume of cases and experience and would, I am convinced, materially improve the end results of chondrosarcoma. If such clinics are available, it is important that suspected cases be referred thereto promptly, before any operative measures, including biopsy, have been undertaken.

Summary

A survey of benign and malignant cartilage tumours has been presented. Emphasis has been placed on the difficulty of distinguishing the benign from the malignant varieties, and on the insidious tendency of the benign to become malignant. The fact that this change is gradual, and that the symptoms are mild at first, makes early recognition difficult; yet because complete removal is often successful in controlling the disease, it is essential that every effort be made to recognize the transition to chondrosarcoma as early as possible.

Implicit reliance should not be placed on the histological picture, but the clinical and roentgenographic evidence should be given great consideration when they suggest the presence of a malignant lesion. In the past there has been a tendency on the part of the profession to postpone radical surgery for too long a period while awaiting a pathological report of frank chondrosarcoma. Earlier and more aggressive surgery can unquestionably bring about an improved prognosis for long-term survival in this group of neoplasms.

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ELECTION TO THE COUNCIL

AS A RESULT of a postal ballot held on Thursday, 4th August 1960, Professor L. N. Pyrah, of the University of Leeds, was elected to the Council in the vacancy occasioned by the death of Sir Archibald McIndoe, C.B.E. The number of Fellows who voted was 2,407.

The result of the voting was as follows:

Elected	*Votes*
Leslie Norman PYRAH	409
Not elected	
Edward Grainger MUIR	311
Norman Leslie CAPENER	275
Norman Rupert BARRETT	273
David TREVOR	262
Alexander Michael BOYD	195
Alan Henderson HUNT	137
Edward Clive Barber BUTLER	131
George QVIST	109
Ronald William RAVEN, O.B.E., T.D.	103
David Napier MATTHEWS, O.B.E.	102
David IOAN-JONES	50
George Henderson MACNAB	37

THE WILSON-BARKWORTH FUND

WE HAVE BEEN asked to publish the following letter received by the President from the Clerk to the Trustees of the Wilson-Barkworth Fund:

"The Trustees of this fund have asked me to write to you, and ask whether there is anything that you or your Council can do to let Members of your College know that help can be given, in suitable cases, towards the payment of fees at Winchester.

"At the present time there are being aided by the Fund no sons of Surgeons at Winchester, and there are only two prospective candidates, both of whom are due to go to Winchester in September, 1961, provided that they pass the Entrance Examination. In one of these cases, the boy's father is dead and his widow is faced with a big educational problem: in the past, the Trustees have been able to help in several cases where the Surgeon found it difficult to educate his family—including an Officer in the Royal Navy and a University Professor."

Anyone interested in obtaining further information should communicate with Mr. W. H. C. Cobb, Clerk to the Trustees, The Wilson-Barkworth Fund, Duncombe Place, York.

FURTHER OBSERVATIONS ON THE AIR CONDITIONING MECHANISM OF THE NOSE

Lecture delivered at the Royal College of Surgeons of England

on

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by

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INTRODUCTION

IN PREVIOUS COMMUNICATIONS I have attempted to elucidate the mechanism of air conditioning in the nose and other parts of the respiratory tract and in my book on the *Comparative Anatomy and Physiology of the Nose* I further elaborated the subject. But in spite of the studies of many authors numerous points of this complex subject still remain unsolved.

If the air conditioning mechanism were directly related to the requirements of the lower respiratory tract it would be expected that there would be dilatation of arterioles and capillaries to warm cold air and filling of sinusoids to moisten dry air. To throw further light on these questions I have, during the last few years, carried out experimental investigations, the result of which, although as yet confusing and incomplete, I propose to record. Many writers have published valuable communications on the same subject, but the purpose of the present paper is to describe a somewhat different approach.

I am fully aware that there is no novelty in many of the conclusions reached, such as the warming effect of expired air, the disadvantages of breathing through the mouth and others; the endeavour has rather been to describe a method of investigation which has some original features by which it may be possible to advance knowledge of this complex subject.

I have, I hope, given credit for the work of others in the *Comparative Anatomy and Physiology of the Nose* and I have not repeated here all the available references, but have appended some which may be of interest to anyone who requires further information.

Not only must the mechanism be considered in respect of warming and moistening of inspired air, but also in relation to other adaptations to assist the sense of smell; furthermore the nose has an important influence on exchanges of gases in the lungs by correlating the entrance and escape of tidal air with the flow of blood through the pulmonary capillaries.

PURPOSES OF NASAL RESPIRATION

Olfaction

The nose came into existence for purposes of olfaction, a function which is the only one in gill breathing fish; lung fish have communication between the nasal organ and the alimentary canal, but again for no other reason than that of olfaction. Similarly in cold blooded amphibia and reptiles this statement appears to be true, since there is no necessity for warming inspired air; moistening of air in terrestrial lower species might be assumed to be an additional function, but the character and small area of the non-olfactory turbinals suggests that this function is but slight.

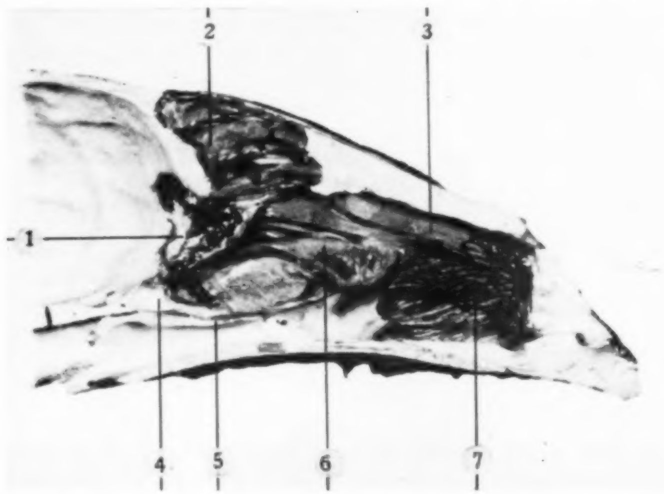


Fig. 1. Sagittal section of nose of a badger (*Meles meles*) to show the relationship of an elaborate branching maxillo-turbinal body (7) to a highly developed olfactory ethmo-turbinal system (6), part of which is accommodated in a superimposed frontal sinus (2) and part in a sphenoidal recess (4). The subethmoidal plate is seen (5) and also the extensive cribriform plate (1). The long naso-turbinal body is also shown (3).

Terrestrial mammals with a keen sense of smell, both herbivora and carnivora, require an elaborate olfactory system with an extensive area of specialized epithelium on a series of ethmo-turbinal bodies; in association with this efficient system there is always found an extensive air-conditioning maxillo-turbinal body, with elaborate reduplication and convolution of its branches to afford adequate surface for the giving up of heat and moisture (Fig. 1).

By saturating inspired air with water vapour entrapping of olfactory molecules is assured, since these molecules are adsorbed on the water molecules and they then carry an electrical charge of opposite order to that of bodily static charges. In consequence the olfactory molecules are attracted to and deposited on the olfactory mucous membrane instead of being wafted down the trachea in the current of inspired air.

Respiration

Respiration of itself does not necessitate entrance of air through the nose; in fact a man when running fast opens his mouth widely and inspires in part through that channel, since cooling and not warming of air is required during times of exertion.

Most mammals breathe through the nose for reasons of olfaction; the epiglottis prevents passage of air through the mouth and ensures that the air stream shall pass over the olfactory turbinals in order to maintain the sense of smell at a high level of acuity.

The relation of nasal respiration to the Hering Breuer reflex, to elimination of dead space air and to pump action on the circulation will be studied later.

For interchange of oxygen and carbon dioxide in the alveoli it is essential that respiratory air should be saturated with moisture.

Ciliary action

Although ciliary streams maintain the health of the paranasal sinuses and nasal fossae, yet they appear subsequent to the development of the nasal organ and are not essential to nasal respiration, as noticed in patients with atrophic rhinitis, whose nasal epithelium is devoid of cilia. Cilia do, however, remove many bacteria and particles of dust and thus give some protection to the lower respiratory tract.

Warming and moistening of air

A secondarily acquired function of nasal respiration is the warming and humidification of inspired air.

Cold air cannot carry much moisture, the absolute humidity being low; when this cold air, even if saturated, is warmed in the nose, the relative humidity drops. It is necessary, therefore, not only to raise the temperature of inspired air so that it may be capable of carrying much moisture, but there must also be provision for the giving up of moisture from the mucosa of the nose, both by secretion and by transudation.

The human nose cannot bring cold air up to body temperature, much of the necessary warmth being supplied by the pharynx, trachea and bronchi.

The retrogressive character of the air-conditioning area in Man, with an attenuated mucosal surface covering small turbinal bodies, is obvious when comparison is made with an animal such as a cat (Fig. 2).

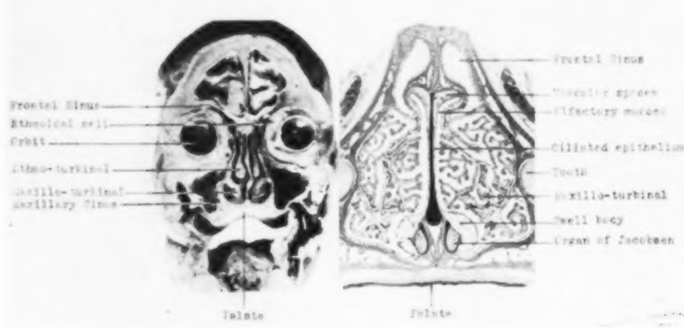


Fig. 2. Transverse sections of the skulls of a Man and of a Cat to show the relative breadths of the nasal fossae, narrow in Man and wide in the Cat; proximity of the flattened ethmo- and maxillo-turbinal bodies of Man to the nasal septum leaves unwanted spaces laterally, in the form of maxillary sinuses. In the Cat the whole breadth of the snout is occupied by widely branching maxillo-turbinals.

CALIBRE OF THE AIR PASSAGES

The narrowest point of the respiratory tract in Man is the internal ostium; the cross sectional area is given by Van Dishoek as between 20 and 40 $mm.^2$, the measurements being approximately 6.3 by 6.3 mm.; there being two nostrils the total available area is between 40 and 80 $mm.^2$. In comparison the glottis when open in quiet respiration is an isosceles triangle 22 mm. by 13.5 mm.; this gives an area of 148.5 $mm.^2$, considerably greater than that of the anterior nasal orifices (Fig. 3).

The figure shows the dimensions of the nose of a human cadaver, which are naturally greater than during life, because of shrinkage of the mucosa; they give a relative idea, however, of the calibre of the airway.

To be added to the narrowing at the internal ostium there is obstruction of varying degree in the nasal fossa, which, although of considerable calibre when the mucosa is shrunken, can be narrowed materially, as far, in fact, as complete closure.

There is a difference between these points of obstruction; the internal ostium varies according to contraction of the muscles in the alae nasi, opening during inspiration and partially closing during expiration; the glottis behaves in a similar manner and appears to afford a fine adjustment in accordance with the requirements of respiration and circulation of blood through the lungs.

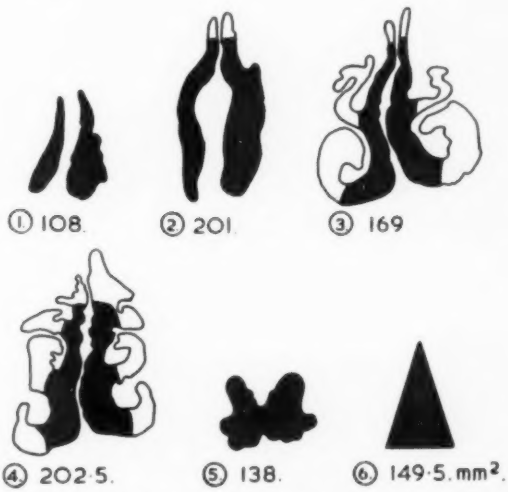


Fig. 3. Cross-sections of the nose of a human cadaver to show the relative calibre available for passage of air: the measurements are in square millimetres. The air spaces under the turbinals are not shaded; there are eddies here but no stream of air. The measurements are all relative owing to shrinkage of the mucosa. The triangular aperture of the glottis is also illustrated as in quiet respiration; it can be enlarged considerably or narrowed to a calibre less than that of the internal ostium. Total length of model 70 mm., section 1 at internal ostium; 2, 10 mm. back; 3 at 30 mm.; 4 at 50 mm.; and 5 at 65 mm.; 6 at glottis.

Obstruction in the nasal fossae, on the contrary, is not rhythmic, and does not vary with the phases of respiration; it is dependent on the degree of engorgement of the mucosa and the swell bodies. The posterior choanae and naso-pharynx are relatively roomy and do not vary in calibre during respiration, nor at any time except as the result of disease.

Obstruction in the nasal fossae varies with the degree of engorgement of the nasal mucosa, but according to Uddstromer the fossae account for only 30 per cent. of this obstruction while the internal ostium is responsible for 70 per cent.

This may be correct in normal noses, but in cases of congestion of the mucosa, as in allergic states or in undue patency of the fossae, as in

atrophic rhinitis, the relative proportions vary. Van Dishoek considers the internal ostium of greater importance in wide noses, accounting for almost all of the respiratory resistance.

When the mouth is open in Man the nasal resistance largely disappears and then the influence of the glottis is of major importance; but during nasal respiration it is probably correct to say that the glottic movements of opening during inspiration and of partial closure during expiration afford the fine adjustment in this pump action.

Even more striking in variability is the relative calibre of the air passages in animals, in many of which the alae nasi are freely mobile, with variation in the ostium from a narrow slit to a freely open passage (Fig. 16).

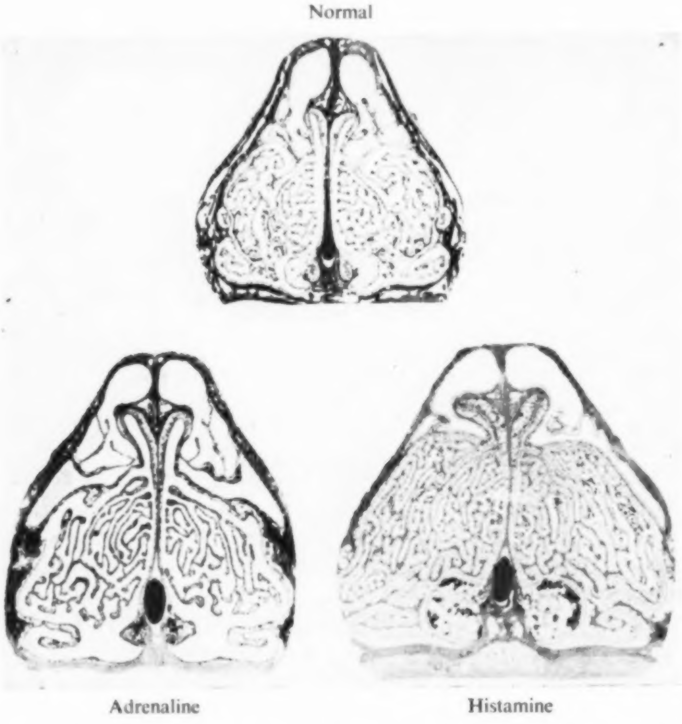


Fig. 4 (*a*). Noses of Cats after perfusion. Sections through maxillo-turbinal region of cats after perfusion with adrenaline and histamine by J. C. Seymour, at the Ferens Institute, Middlesex Hospital Medical School, showing extreme constriction and engorgements.

The patency of the nasal fossa is subject to a considerable degree of change, owing to swelling of vascular spaces in the mucosa covering the many branches of the maxillo-turbinal body; this is demonstrated forcibly in the nose of cats perfused with adrenaline or histamine (Fig. 4).

Normal

Adrenaline Histamine

Fig. 4 (*b*). Noses of Cats after perfusion. Sections through ethmo-turbinal region of cats after perfusion with adrenaline and histamine by J. C. Seymour, at the Ferens Institute, Middlesex Hospital Medical School; the changes are very slight.

INFLUENCE OF RETARDATION OF AIR FLOW THROUGH THE NOSE

The internal ostium is a very obvious point of constriction at the inner termination of the nasal vestibule, with particular influence during inspiration; its calibre can be reduced or increased by contraction or dilatation of the alae nasi under the control of their muscles. Contraction of certain of these muscles during inspiration, with dilatation of the alae nasi, allows free entrance of air and their relaxation increases obstruction during expiration, thus balancing the volumes of tidal air, according to some observers. One-sided facial paralysis eliminates muscular opening and causes increased naso-pharyngeal pressure (Uddstromer).

Further obstruction is produced by friction in the nose, at the larynx and in the bronchi and bronchioles; according to Hilding, there are about 50,000 terminal bronchioles in Man.

Elimination of dead space air

I have previously stressed the importance of these nasal movements in elimination of dead space air, as may be observed in a horse on a cold day, when moisture in the expiratory stream of air condenses; movements of the nostril are associated with changes in the calibre of the trachea, in which there is, in horses, a broad band of muscle. There is obvious opening of the nostril during inspiration as a result of muscular contraction, and in a fast-running animal like the horse there also appears to be active muscular closure during expiration to expel dead space air.

Bronchoscopic observations in Man show similar movements of contraction in the smaller and larger air passages during expiration, with reduction of dead space by what appears to be a peristaltic action, contraction of the alae nasi being the terminal part of the mechanism.

Hering Breuer reflex

Another result of nasal obstruction is slowing of the phases of respiration because of delay in the Hering Breuer reflex, thus affording more time for respiratory exchanges in the lungs, where diffusion is the most important factor.

Olfactory acuity

Obstruction at the front of the nose causes air to enter the wider nasal fossae more slowly than if there were no internal ostium, and consequently the current of air spreads out and has more time to deposit olfactory molecules on the ethmo-turbinals.

Similarly for purposes of air conditioning, this delay gives more time for the taking up of heat and moisture during inspiration and for the giving up of moisture with its contained heat during expiration.

When the noses of carnivora are examined, with their intricate and widely branching maxillo-turbinal system, it is obvious that considerable delay must take place in the passage of inspiratory and expiratory tidal air; preliminary slowing at the internal ostium assists in this process (Figs. 5 and 6).

Pump action on the circulation

In a Hunterian lecture given in 1925 and subsequently in books on *The Mechanism of the Larynx* and its successor *The Comparative Anatomy*

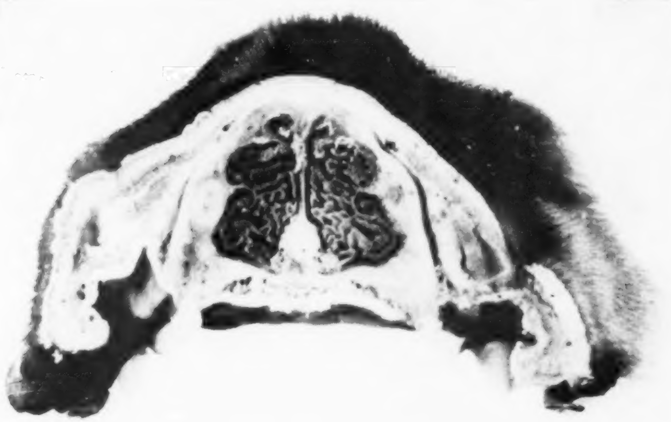


Fig. 5. Section across the snout of a dog to show the widely branching maxillo-turbinal body; there are no empty lateral air spaces as in Man.

and Physiology of the Larynx I ascribed an important function to movements at the glottis during respiration affecting the circulatory system. The observation put forward, although not entirely original, was that the aperture of the glottis varied during inspiration and expiration to regulate the passage of air, whereby there was correlation between the volume of air entering the lungs and the blood flow through the pulmonary capillaries.

There is no useful purpose for the entrance of a large volume of air when there is little blood in the lungs, since giving up of oxygen and removal of CO_2 is then inefficient; regulation of air flow in relation to blood flow

ensures that an optimum volume of air shall meet a corresponding volume of blood. Even with this regulating action tidal air does not enter the lungs at a completely uniform rate, there being a peak.

This concept is now recognized in assessment of respiratory efficiency by the so-called ventilation perfusion ratio, which is

$$\frac{\text{Pulmonary Ventilation per minute}}{\text{Pulmonary Blood Flow}}$$

Cetacea have a mechanism whereby blood is held up in venous spaces in the liver when the animal is submerged, with release of blood flow through the lungs at the moment of entrance of tidal air when the surface is reached and the blow hole is opened.

Obstruction to entrance of air into the trachea produces a reduced pressure in the thorax and this in turn exerts a suction action on the right side of the heart and great veins, causing free intra-pulmonary circulation through dilated pulmonary capillaries; conversely, during expiration, obstruction to the escape of air raises intra-thoracic pressure and reduces circulation through the pulmonary capillaries at a time when there is insufficient fresh air to give up oxygen and to remove carbon dioxide. Resistance is greater with nasal than with oral respiration.

No doubt I ascribed over much importance to the obstructive regulating mechanism at the glottis, attaching too little importance to retardation of air flow through the nose.

ANATOMY OF THE AIR CONDITIONING AREA IN THE NOSE

In cold blooded animals such as lung fish, some amphibia and reptiles, there is, in most species, no provision for the warming and moistening of air, and in others there is only a small area of specialized mucosa.

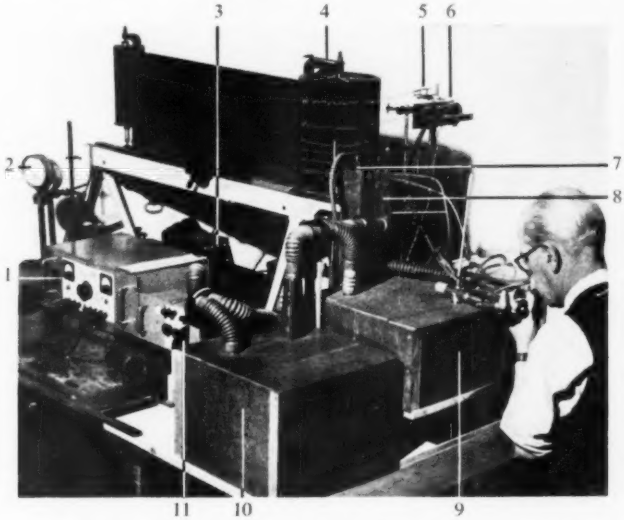
Birds have a peculiar method of respiration and of warming or cooling the body and in them the nose is not of so much importance for air conditioning as in mammals; in many species, particularly in Gannets, Cormorants and Pelicans (Pelicaniformes), there are no external nostrils and consequently no passage of air through the nose.

Keen scented mammals have elaborate ethmo-turbinals and air conditioning systems, as stressed in previous communications; the important structure for the latter purpose is the maxillo-turbinal body, which in some is long and convoluted and in others widely branching, with a very extensive area available to give up heat and moisture during inspiration or to regain both during expiration (Figs. 2, 4 and 5).

It is unnecessary to describe these structures, because the subject has been fully studied elsewhere, particularly in my book on *The Comparative Anatomy and Physiology of the Nose*.

Nor need the different means of providing moisture be referred to, whether from the external atmosphere, by transudation, or by secretion of serous and mucous glands.

The higher Apes and Man rely mainly on vision and not on scent for identification of food and for recognition of friend or foe; in them the areas of both olfactory and air conditioning surfaces are very much reduced (Fig. 2). In consequence experimental studies of air conditioning in Man are somewhat confusing; the relatively small area of epithelium capable of giving up heat and moisture, although inadequate for a keen sense of smell, is sufficient for human respiratory needs, but only with the assistance given by the mucosa of the trachea and bronchi.



(1) D.C. Amplifier. (2) Hygrometer. (3) Time marker. (4) Kymograph. (5) Tambour for respirations. (6) Electromagnet for temperature. (7) Manometer for naso-pharyngeal pressure. (8) Anterior nasal manometers. (9) and (10) Cooling chambers. (11) Air pump.

Fig. 6. Apparatus for investigating response of nose to changes of temperature and humidity.

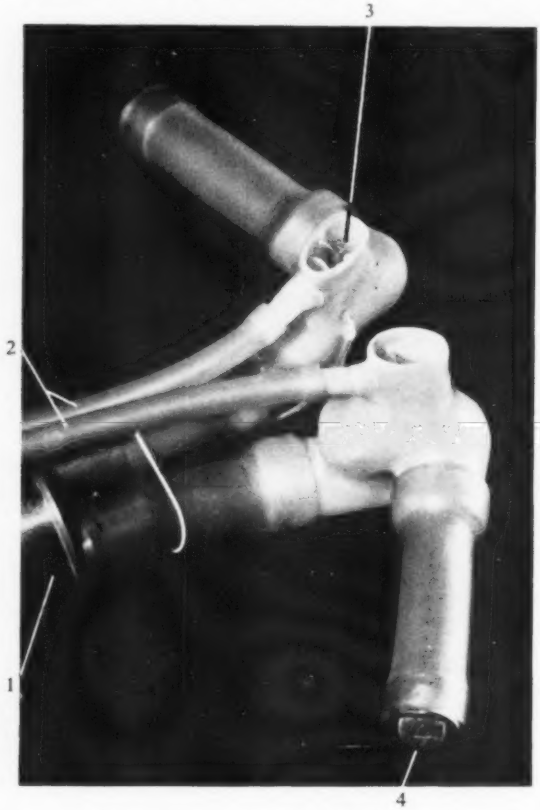
EXPERIMENTAL STUDIES IN MAN

It is obvious that the giving up of heat from the nose is dependent on dilatation of arterioles and capillaries, with an increased blood supply when warming of air is required; and that for humidification engorgement of sinusoids in the mucosa is required when dryness of the atmospheric air calls for the supply of moisture.

It was to study the mechanism whereby these requirements are fulfilled that the investigations to be described here were carried out.

Measurement of pressure in the naso-pharynx

The intention has been to determine the degree of resistance due to shrinkage or swelling of the mucosa in the nasal fossae by recording the reduced or increased pressure in the naso-pharynx; although the influence of the internal ostium is fully realized it is still obvious that there is additional obstruction to the flow of air in the nasal fossae and this is clearly shown in Kymographic tracings, derived from a curved tube in



(1) Connection to air supply. (2) Tubes for anterior nasal pressures. (3) Thermo-couple in nose-piece. (4) Expiratory valve.

Fig. 7. Nasal connections.

the roof of the mouth attached to an oral shield to make the system airtight; the tube is connected to a manometer writing directly on smoked paper. Air is supplied by a pump, which, although capable of delivering about 20 litres a minute, does so at a very low and almost negligible pressure; the current of air reaches the nose through two plastic tubes fitting the nasal vestibule and of a sufficient size to prevent alteration of the calibre of the internal ostium by contraction of muscles in the alae nasi (Figs. 6 and 7).

Each nasal airway has built into it two flap valves of the type used with tracheostomy tubes, one opening on inspiration and the other on expiration. The valves offer scarcely any resistance and ensure a one-way flow of air; the subject takes air in effect from the side of the delivery tube, any excess air escaping through the expiratory valve (Fig. 7). Comparison with a face mask shows that these nose pieces do not cause obstruction. To record the pressure at each nostril there is, in each nose piece, a side tube turned at a right angle to face the expiratory stream, responding to the positive pressure of expiration and to the suction effect of inspiration; each of these side tubes is connected to a water manometer. This method appears better than that in which one nostril is plugged and is connected to a manometer.

To give a tracing of the phases of respira'ion a stethograph encircles the subject's chest; it is connected to a tambour writing on the smoked paper.

Measurement of naso-pharyngeal pressure is no indication of air flow, but merely shows the degree of resistance offered to inspiration and expiration; with sufficient respiratory effort a high degree of resistance can be overcome.

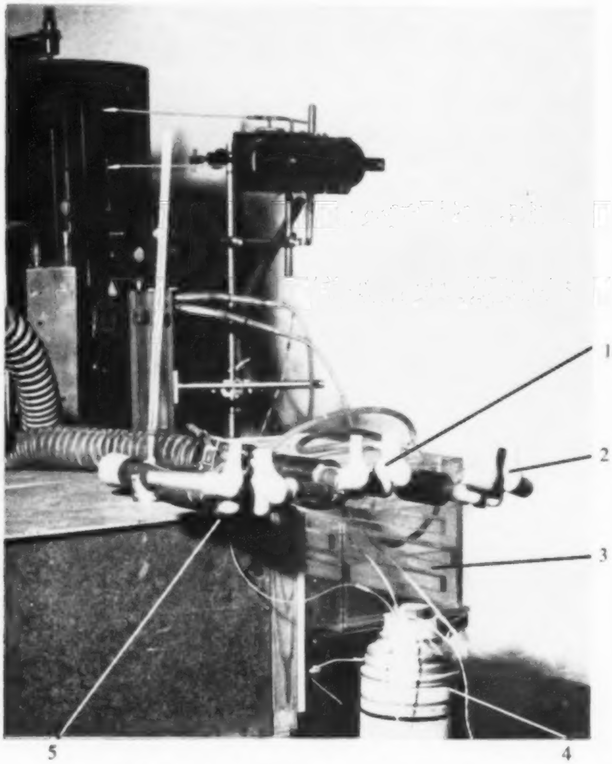
The manometer attached to the anterior nasal airways does, however, indicate the relative airflow through each nostril, within certain limits.

Control of temperature

The tube from the air blower leads to two cooling chambers and passes through coiled ducts surrounded by methylated spirit containing CO_2 ice; by this means the air can be brought down to a minimum temperature of -63° C. (-82° F.) (114° frost F.), which is lower than any encountered under the most extreme climatic conditions. In the passage of this frozen air through the two nose pieces and their connecting tube there is a rise in temperature and when the air reaches the nostril it has risen to about -40° C. (-40° F.) (72° frost F.) or higher if the air at source is above -60° C. The temperature of the air actually entering and leaving the nostril is recorded by a fine thermocouple, five-thousandths of an inch in diameter, connected to a D.C. amplifier and thence to an armature suspended between two electro-magnets, writing directly on the smoked paper through a long arm; a thermocouple of this type is very sensitive, with no lag.

The amplifier was kindly made available by the Medical Research Council.

The blower can also deliver room air to a second nose piece, while hot



(1) Room air. (2) Hot air. (3) Hot air mixer. (4) Temperature control. (5) Cold air.

Fig. 8. The three nasal connections for varying temperatures.

air is obtained from a chamber connected to a hot tube with an element controlled by a rheostat; this requires a third double nose piece (Fig. 8).

By this method the effects noted are entirely due to the nose and not to any skin effects, as are inevitable in methods where the subject's body is exposed to hot or cold atmospheres.

Control of humidity

Dry air. Air cooled to several degrees below zero is almost entirely dry, moisture being frozen out and deposited as crystals; very cold air cannot carry water vapour and actual recordings by the Meteorological department of the Royal Air Force made available to me by Dr. Goldie

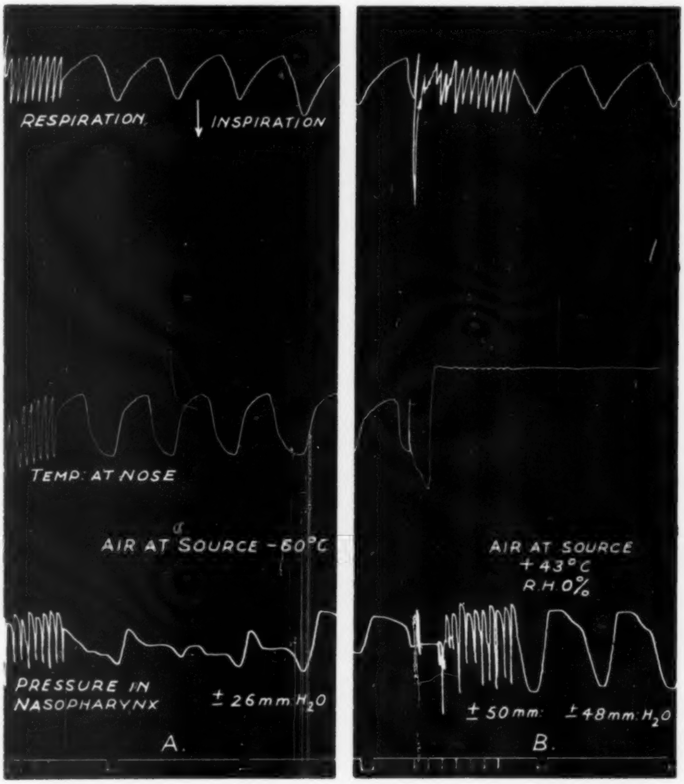


Fig. 9. A subject breathing very cold air with recording of the naso-pharyngeal pressure (*a*); when hot dry air is breathed resistance in the nose increases owing to filling of sinusoids and the naso-pharyngeal pressure rises (*b*).

show that in the stratosphere, at a height of 35 to 40,000 feet, the relative humidity is down to 1 per cent. with temperatures of about –70° F. (–56.6° C.) or lower.

The air delivered to the nose piece can be considered as completely dry, and if passed through the heating system it will still be dry.

Very wide tubes and rotating valves must be employed to prevent blockage by the large amount of frozen moisture deposited.

Moist air. Atmospheric air in a room is at varying degrees of relative humidity recorded by a hair hygrometer; the figures appear on various tracings.

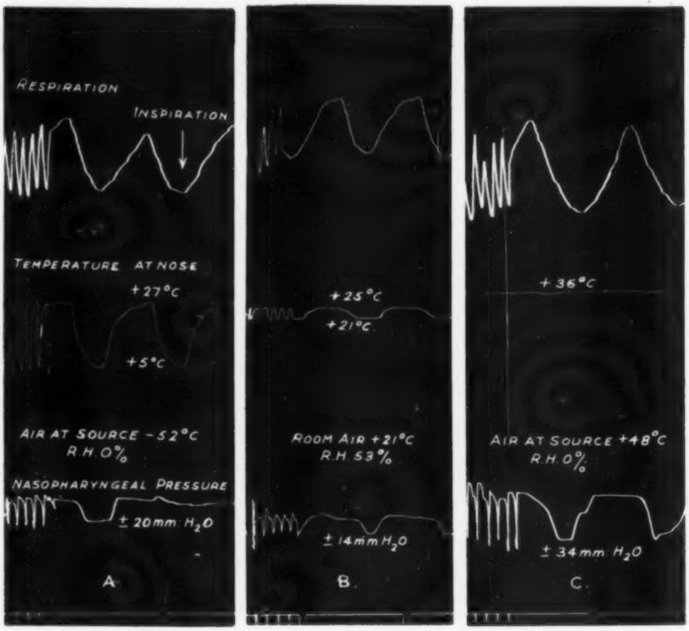


Fig. 10. The effect of varying temperatures on the nasal mucosa. In (*a*) air reaches the nose at about −30° C.; the expiratory current helps to warm incoming air, as seen in the tracing. The naso-pharyngeal pressure is low. In (*c*) hot dry air causes increased nasal obstruction due to filling of sinusoids, with a consequent rise of naso-pharyngeal pressure. (*b*) shows the effect of air at room temperature and at a comfortable degree of humidity.

To produce very moist or saturated air a steam kettle is employed, which will give as much moisture as required, the air passing through it being subsequently cooled to the requisite temperature.

By these means air can be delivered to the three nose pieces at any degree of temperature or humidity, cold dry, cold moist, warm or hot dry or moist.

The whole apparatus, including the thermocouples and electrical recording magnetic device, have been designed, elaborated and made in the Physiological Department of the Royal College of Surgeons of England by Mr. S. Steward; the difficulties of construction have been considerable and perseverance during several years has been necessary to reach the final result.

In a research of this description patience is required, for a long time had been spent in preparation before any results could be obtained, and even then the value of the observations made are in doubt; however, this is inevitable and disappointment at the slowness of progress must be avoided.

EFFECT OF DRY COLD AND HOT AIR ON NASAL MUCOSA IN MAN

The first series of experiments was intended to show the effect of cold or hot air on the arterioles and capillaries and vascular spaces of the epithelium, air at room temperature and humidity being used as a control.

It might be conjectured that very cold air would cause dilatation of arterioles and capillaries to warm the ingoing current, with filling of sinusoids to give up moisture to remedy the extreme dryness. With hot dry air it would appear that filling of sinusoids would be required, while capillaries would have no need to dilate. In point of fact cold air, in comparison with hot air, causes shrinkage of nasal mucosa as shown by a freer airway and lowering of naso-pharyngeal pressure; this change is not invariable but usual (Fig. 9).

Hot air shows swelling of mucosa with a rise in naso-pharyngeal pressure (Fig. 9), as expected, while moist room air shows intermediate changes (Fig. 10); in some subjects this change is not obvious. Measurements of anterior nasal pressures are greater when cold air is breathed than with either hot air or air at room temperature; the relation to air flow is not obvious, but some indication is given of relative patency (Fig. 11).

Dry air at room temperature

Air is passed through the cold tubes to freeze out moisture and is then brought up to the desired temperature; at 22° C. and completely dry the naso-pharyngeal pressure was 30 mm. H_2O, as compared with 26 mm. H_2O when very cold air was used and with 28 mm. H_2O with hot dry air. The reason for the differences is no doubt the necessity to warm and moisten the air at 22° C., with dilatation of capillaries and filling of sinusoids. When cold air is breathed there is reflex constriction of arterioles and capillaries in unison with that of skin capillaries; with hot dry air humidification is required but no warming. The depth and rate of respiration remained constant in all three readings (Fig. 11).

Response to moist air

Air at a comfortable temperature (18° C. to 25° C.) and agreeable relative humidity (40 per cent. to 60 per cent.) leaves the nasal mucosa in its normal state of moderate engorgement (Fig. 10 (*b*)); since inspired air has eventually to be brought up to body temperature (37° C., 98.4° F.) and to saturation point, it is obvious that the capillaries must be at a degree of dilatation sufficient to give up heat; and the sinusoids must be

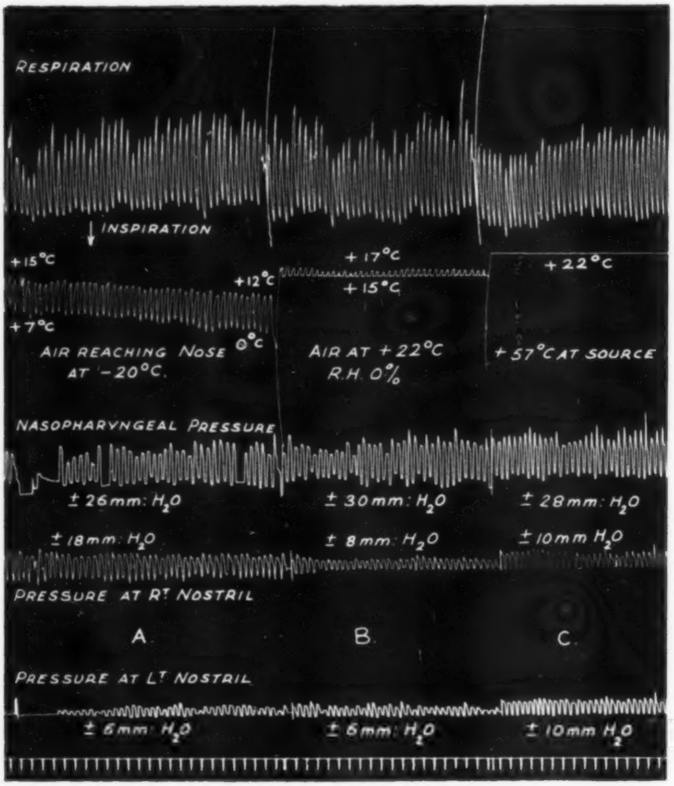


Fig. 11. Comparison of dry air at different temperatures. The naso-pharyngeal pressure is greatest with dry air at room temperature (*b*) owing to the necessity of both warming and moistening inspired air; it is slightly above normal limits with very cold air (*a*) and a little higher with hot dry air (*c*). The anterior nasal pressures are recorded, but their relation to air flow through each nostril has not been determined.

sufficiently distended to transude moisture. These changes are shown by a naso-pharyngeal resistance of between 14 mm. H_2O or as high as 28 mm. H_2O, an average of $\pm$21 mm. H_2O.

To determine the normal limits when no blower or nasal valves were used, naso-pharyngeal pressures were measured; in three subjects the readings were 11, 12 and 18 mm. H_2O very close to those recorded when the blower and nasal valves were in action.

To decide whether the valves on the air ducts were adequate and that the degree of opening allowed sufficient air to pass to avoid resistance, measurements were made; these show that when the valves were two-thirds or even one-half open, the naso-pharyngeal pressure was 20 mm. H_2O, which is normal.

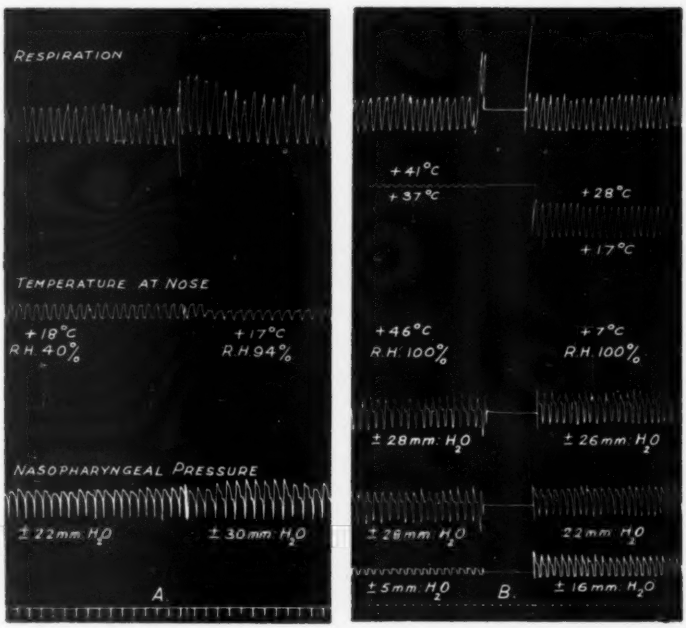


Fig. 12. With a constant temperature a rise of relative humidity causes a rise of naso-pharyngeal pressure. Temperature 18° C. R.H. 40 per cent. pressure of $\pm$22 mm. H_2O (*a*), and with 17° C. R.H. 94 per cent. pressure in naso-pharynx of $\pm$30 mm. H_2O, indicating increased resistance in the nose. With hot saturated air of 46° C. and 100 per cent. R.H. the nasal resistance is slightly greater than with colder air of 7° C., also saturated (*b*). The anterior nasal pressures in (*b*) are: Right 28 mm., left 5 mm. H_2O and 22 mm. right and 16 mm. H_2O left, indicating some opening up of the left side of the nose.

Figure 12 indicates increased obstruction in the nose with a rise of humidity, the temperature being constant; thus (*a*) at 18° C., with a relative humidity of 40 per cent., shows a naso-pharyngeal pressure of 22 mm. H_2O, within normal limits, while at 17° R.H. 94 per cent. the pressure is raised to 30 mm. H_2O. This change may be due to deposition of moisture in the nose as a result of oversaturation.

With saturated air, cold air allows freer passage through the nose, there being no condensation as with hot air. In tracings (*b*) the left side of the nose opens with cooling of the air, a response already referred to.

Summary of results in Man

These experiments have been lengthy, because it takes an hour or two to set up the apparatus so as to produce air at the requisite temperature and humidity; freezing of the nose pieces and valves must be corrected.

The Kymograph has to be prepared with all five writing points in correct contact and with manometers at the right level. On very many occasions something goes wrong and even when all is ready some volunteers are unable to manipulate correctly the nose-pieces and pressure tube in the mouth; in consequence the number of experiments is necessarily limited, but it will be possible, after this preliminary preparation of some years, to amplify the investigation.

On summarizing the results the following conclusions have been reached:

(*a*) Swelling of the mucosa was less with cold air than with air at room temperature in five out of seven instances with one other equal.

(*b*) Swelling was less with cold than with hot air in eight out of 12 experiments, with one other equal.

(*c*) Swelling was less with moist air at room temperature than with hot air in 10 out of 15 occasions, with three in addition equal.

(*d*) Dry air at room temperature causes greater swelling of the mucosa than moist air because of dilatation of capillaries and filling of sinusoids.

Shrinkage of the mucosa with cold dry air is related to constriction of capillaries in the skin generally and is greater than when air at room humidity and temperature is breathed; and swelling of the mucosa with hot dry air is greater than with either room air or very cold air.

The average temperatures at the nose were cold air −30° C., hot air +41° C. and room air +21° C.

A factor confusing the results was that in some subjects, no doubt due to the structure of the nose, all readings of pressure were low, whilst in others they were all high.

It seems best to draw conclusions from typical cases such as those recorded in Figures 9 and 10. When comparing very cold and hot air with moist room air it must be noted that the latter is at a degree of humidity of from 40 per cent. to 66 per cent.; there is consequently not the same need for engorgement of sinusoids as with cold and hot air, in both of which the air was dry in these experiments.

Observations by Spratt showed constriction of nasal mucosa to be more usual in cold air and Ballenger noticed that the erectile bodies are enlarged in dry air. A method used by Ralston and Kerr was the insertion of a rubber balloon in one nostril to record change of volume. Observations on the same subject have been made by Stoksted, Heetderks and Ingelstedt.

DISTRIBUTION OF AIR FLOW THROUGH THE NOSE

There are, of necessity, variations in the volume of air passing through the right and left sides of the nose due to deflection of the nasal septum or to abnormality in the turbinal bodies. But, allowing for these structural differences, there are changes from time to time referred to as the nasal cycle, to be considered later; and there are also changes dependent on the temperature and humidity of the air entering the nose.

It was hoped that an estimation of the pressure in each nasal insert might give an indication of the air flow through the nasal fossae; the small channels in each nose-piece are upturned, facing the expiratory stream, and in consequence the movement of the floats in the two manometers is greater during expiration than during inspiration. It is possible, however, to separate the two phases, but even so the tracings vary greatly and cannot be used to determine the actual air flow in litres per minute (Figs. 11 and 12 (*b*)).

Attempts have been made to obtain a more accurate estimate with flow meters connected to each nasal insert, but so far without success.

Estimation of air flow with a pump

By the kind co-operation of Professor Woolmer and some members of his department measurements were made of the volume of air and its pressure in passing through an artificial nose by compressing one or other of right and left wide bore tubes; the relation of pressure to air flow could be measured by means of a two-liquid manometer and two air flow meters, air being drawn through by a pump. The results do not, however, give help in interpreting the air flow through each human nasal fossa as recorded with water manometers connected to each nasal insert.

The nasal cycle

The work of Heetderks showed that air does not pass equally through both nasal fossae, but that there is a partial change over, usually at inter-

vals of 50 mins. to 4 hours; this change is irrespective of any permanent inequality, such as may be caused by deviation of the nasal septum.

Examination of these changes with our apparatus confirms the variation, even as frequently as at half-hourly intervals, but the differences do not appear to be great. A series of tracings shows the pressure changes in the naso-pharynx when breathing through one nostril only and demonstrates the variation of pressure during one-sided nasal obstruction with one nostril closed, compared with that when both sides are open. The naso-pharyngeal pressure variations are definite, but slight:

		Both sides open mm. H_2O	*Right only*	*Left only*
A	3.0 p.m.	24	28	41
B	3.45	17	40	31
C	4.17	27	26	33

ADAPTATION TO CHANGE OF TEMPERATURE

Cold dry air reaching the nose at -7° C. (19° F.) over a period of thirty minutes shows no obvious indication of adaptation, the naso-pharyngeal pressures changing only 4 mm. H_2O, a negligible amount, from 18 to 16 to 14 mm. H_2O.

During the same period the anterior nasal pressures indicated a slightly greater air flow through the left side of the nose than through the right; both right and left showed a very slight reduction subsequently, apparently due to reduced depth of respiration.

WARMING OR COOLING EFFECT OF EXPIRED AIR

Cold air. It might be thought and was in fact expected by me that the breathing of very cold air at temperatures as low as -40° C. (-40° F.) would have some harmful effect, either in causing frost bite of the nose or oedema of the larynx or lungs; the stories of freezing of the lungs in the Arctic do not appear to have any foundation.

Continuous measurements of the air current at the nostril recorded in numerous tracings show that there is a gradual drop in temperature during inspiration and a rise in expiration; this is due to the warming effect of expired air, which leaves the finer bronchioles at +37° C. and is gradually cooled as it reaches the larger bronchi, the trachea, larynx, pharynx, naso-pharynx and the nose. During this journey moisture is given up owing to the drop of temperature and lowering of absolute humidity and this moisture carries with it a considerable degree of heat, which is used to warm the incoming current.

This warming effect is well shown in many of the records; for instance it is found that air reaching the nose at $-7°$ C. (19° F.) is prevented from chilling the nose, the lowest temperature recorded at the end of inspiration being $+8°$ C., dropping later to $+5°$ C. and again rising at the end of the experiment to $+8°$ C.; at the end of expiration the level is $+25°$ C. and later $+19°$ C. rising again to $+20°$ C.

Figure 10 shows that air at $-52°$ C. at source, reaching the nose at about $-30°$ C. never drops below $+5°$ C. as it enters the nose and is raised to $+27°$ C. at the end of expiration; in another experiment the minimum is $+7°$ C. and the maximum $+20°$ C. with air reaching the nose at about $-29°$ C. Again, air at $-25°$ C. reached a temperature of $+7°$ C. at end of inspiration and $+26°$ C. at end of expiration.

Fig. 13. Drawing of an Eskimo with the hood of the parka fringed with wolverine fur, which prevents the formation of icicles; in necessity, the face is turned sideways so as to breathe through the fur.

These figures illustrate the remarkable warming effect of expired air, with conditioning of the current to a level above which it can be further raised in the air passages so that it shall eventually reach the alveoli at $+37°$ C.; no account has been taken of the subsequent levels in naso-pharynx, pharynx, trachea and bronchi, these having been recorded in other publications by many authors.

Examination of Eskimos inhabiting the Arctic showed that they have no special mechanism in the nose to warm air, but that they rely on a fringe of wolverine fur projecting beyond the nose for four inches and thus making

a trap to hold warm expired air, ready to raise the temperature of the incoming stream; this trap is greater than in the present experiments, where the dead space in the nose pieces is very slight (Fig. 13).

Room air. With air at a higher temperature the changes are less marked and at a higher level.

Thus air at +21° C. (70° F.) and R.H. 53 per cent. in a room enters the nose slightly above this temperature at 23° C. owing to the warming effect

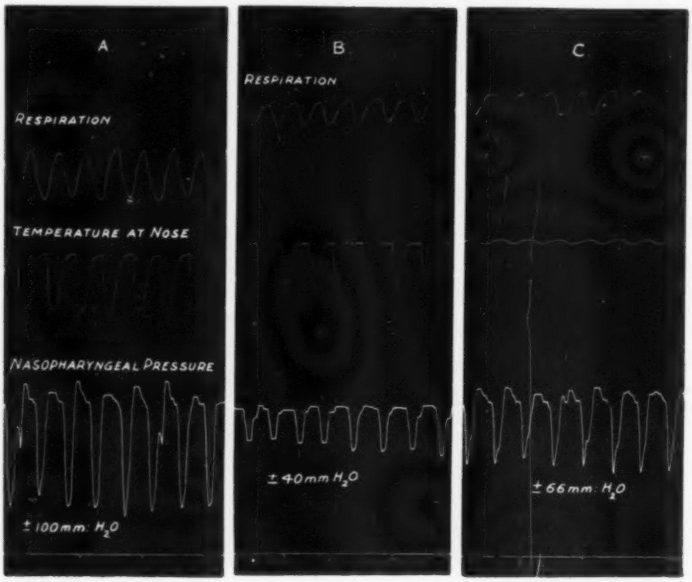


Fig. 14. When cold air enters through one nostril only resistance in the nose rises considerably, as indicated by the high naso-pharyngeal pressure (*a*); when both sides of the nose are open the pressure is considerably lower (*b*). Hot dry air causes dilatation of sinusoids with considerable resistance in the nasal fossae (C).

of air leaving the alveoli at +37° C.; at the end of inspiration it is at +21° C.

In Figure 10, the expiratory air in a room at 21° C. with R.H. 53 per cent. rises to 25° C. but is still well below the core temperature of the body (+37° C.) (98.4° F.).

This shows that expired air loses heat as it passes through the bronchi, trachea and naso-pharynx, as has been well recognized by other observers, using better methods for measuring temperature.

When room air is breathed through nasal fossae whose mucosa has been shrunken with cocaine, the expiratory rise is less.

Hot air. Hot air produces some cooling effect; thus in Figure 10 (*c*) air at +48° C. at source enters and leaves the nose at +36° C. In Figure 12 (*b*), air saturated with moisture entering at the end of inspiration at +37° C. leaves at +41° C., while cold air at +7° C., also saturated, shows figures of +17° C. and +28° C.

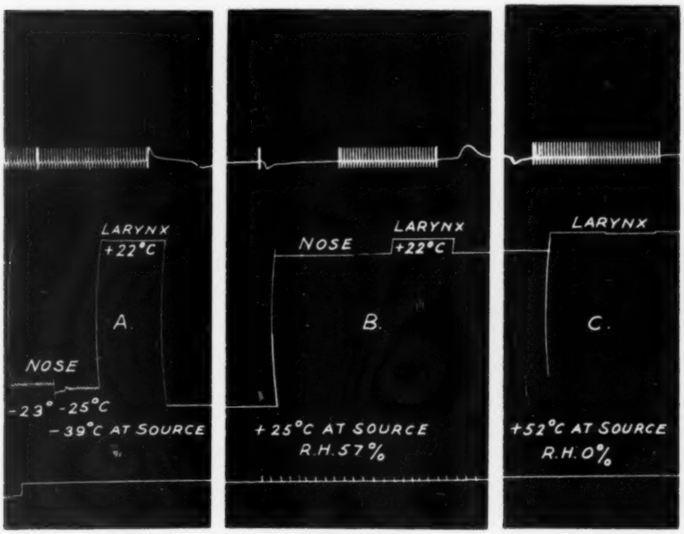


Fig. 15. Air was drawn at 32 strokes per minute, with a minute ventilation rate of 8 litres, through the nose of a man whose larynx had become separated from the trachea as the result of an accident. Air at source of −39° C. reaching the nose at −23° C. to −25° C. is raised after passing through the nose to +22° C. at the lower end of the larynx into which a rubber tube was inserted (*a*). With air at +25° C. R.H. 57 per cent. the temperature below the larynx was +22° C. (*b*), and with hot air at +52° C. R.H. 0 the laryngeal temperature was again +22° C. (*c*). This experiment shows that the nose alone can, in the absence of warm expired air, raise the temperature of inspired air, but not up to body level.

These observations show that there are considerable fluctuations in the temperature of air entering or leaving the nose, dependent on the external temperature.

EFFECTS OF ONE-SIDED NASAL OBSTRUCTION ON PRESSURE

If the tidal volume of 500 c.c. of air is to be maintained, greater effort is required by the respiratory muscles when one side of the nose is partially or completely obstructed.

Figure 14 illustrates the greatly raised naso-pharyngeal pressure when breathing with the left side closed (*a*); when both nostrils admit air this pressure is more than halved (*b*). In another trial the naso-pharyngeal pressure with both nostrils of almost equal calibre was 14 mm. H_2O, while with the left side closed it was 30 mm. H_2O; similarly with hot air at $+55^\circ$ C. the pressures were respectively 26 mm. and 40 mm. H_2O. Obviously long-standing unilateral obstruction is undesirable.

EFFECTS OF ONE-SIDED OBSTRUCTION ON TEMPERATURE

With slight variation in air flow through the two sides of the nose the temperature changes remain constant whether one or other nostril is patent.

Air at $+55^\circ$ C. remained at a level of $+37^\circ$ C. and $+40^\circ$ C. at termination of inspiration and expiration whether one or both nostrils were open.

Usually, when one nostril is closed, as shown in Fig. 14 (*a*), the warming effect is reduced; the temperature at the end of inspiration is considerably lower than when both sides of the nose are in action (Fig. 14). There is, however, little difference at the end of expiration.

WARMING DURING INSPIRATION ALONE

An experiment was carried out on a patient whose larynx was separated from the trachea as a result of accident. A tube was inserted into the open lower end of the larynx and air was drawn through by a series of suction pulses; the pump was working at 32 per minute with a volume of 8 litres per minute.

Thermocouples were placed in one of the nasal tubes through which cold air was delivered to the subject's nose and a second thermocouple was at the lower end of the larynx.

Air reaching the nose, first at -25° C. and later at -37° C. was raised to a temperature of $+22^\circ$ C. after passing through the nose, naso-pharynx, pharynx and larynx (Fig. 15 (*a*)).

Room air at $+25^\circ$ C. and relative humidity 57 per cent. reached a temperature of $+22^\circ$ C. at the larynx (*b*), while hot air at $+52^\circ$ C. R.H. 0 per cent. was reduced to the same level (*c*). Since only a single experiment was carried out, the results are not conclusive and further investigations are required, provided subjects with a laryngeal or tracheal fistula are available.

A similar experiment on a dog with a tube inserted just below the larynx showed that air reaching the nose at -20° C. was raised at the larynx to

+33° C.; in this case the warming is carried out by the nose and nasopharynx, since the latter communicates directly with the larynx, the pharynx being negligible in capacity.

The experiment was carried out by delivering very cold air to the dog's nose through a conical mask; in the mask there was a thermocouple to record the temperature of ingoing air.

A second thermocouple was fixed in the trachea, just below the larynx, and below this a rubber tube, directed towards the larynx, was connected to a pump which drew air through the nose at a rate of 17½ per minute and with a stroke volume of 250 c.c., which equals 4.37 litres per minute.

Fig. 16. Transverse sections across the nose of a Grey Seal (*Phoca vitulina*). Above, through the sieve-like maxillo-turbinal body; below on left at the commencement of the nasal fossae; and below on right through the slit-like internal ostium.

A tube for the dog's natural respiration was placed in the lower trachea. The work imposed on the nose was considerably greater than under natural conditions since the dog's respiration rate was six with a ventilation volume of 1.4 litres per minute as compared with 4.37 litres, a proportion of 3.1 to 1.

EFFECT OF BREATHING THROUGH THE MOUTH

With air reaching the nose at –35° C., inspired through the nose and expired through the mouth, the reading at the nostril at the end of inspiration and expiration was –30° C., indicating the almost complete loss of expiratory warming.

Air was breathed in and out through the mouth, delivered at a temperature of –35° C.; at the end of inspiration the level at the mouth was –25° C. and the end of expiration –5° C.; there is obviously some warming, but not as much as with nasal respiration.

Conclusions

It has been found by some observers (Cole, etc.) that warming of inspired air is almost as efficient with oral as with nasal respiration, but the records given above do not confirm this, probably because of different methods. More conclusive is the evidence of comparative anatomy which shows, in a great number of mammals, a freely branching and sieve-like maxillo-turbinal body, designed, not only to warm and moisten inspired air, but also to retain heat from the expiratory stream, which otherwise would be lost.

Similar results in retention of heat can be obtained by wearing a finely perforated copper shield over the mouth; unfortunately the resistance to air flow of this contrivance precludes its adoption. A maxillo-turbinal system of great value in retention of heat, although not wanted for olfactory purposes, is present in seals (Fig. 16).

A knowledge of the benefits derived from nasal respiration, with its efficient retention of heat from expired air, helps the design of an apparatus for subjects of tracheostomy or laryngectomy, in whom the assistance of the nose is partially or completely lost; the aim should be the creation of considerable dead space, where incoming air can be warmed by the outgoing current.

The bad effects of nocturnal mouth breathing are largely avoided by the use of an oral shield, which effectually prevents entrance of air through the mouth.

RESULT OF SLOW BREATHING

The conditioning of cold air occurs when air enters through both nostrils at a normal rate of 15 or 16 per minute; when breathing is abnormally slow the warming effect is much less.

At 16 respirations per minute, with air reaching the nostril at -35° C. (-31° F.), at the end of expiration the temperature rises to +13° C. and after four minutes to +9° C.

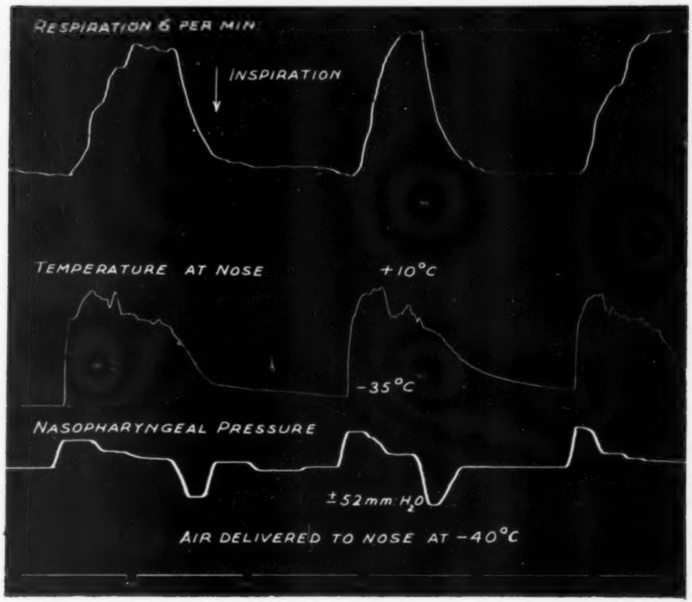


Fig. 17. The tracing shows the effect of breathing cold air at a slow rate; with a respiration rate of 6 per minute the air at the end of inspiration enters the nose at -35° C., having reached the nostril at -40° C., in the absence of warming by expired air. At the end of expiration the temperature at the nostril was +10° C.

The observation to be recorded here is that with a respiration rate of 5½ per minute, the depth being greatly increased, the warming effect of expired air has less opportunity of functioning and at the end of inspiration the temperature dropped to -18° C., rising to +15° C. at the end of expiration.

The naso-pharyngeal pressure was low and the air flow through the nose was high, both being slightly raised during slow breathing.

Figure 17 shows this effect, where a respiration rate of 6 per minute allows air delivered to the nose at -40° C. to pass into the nose at -35° C. at the end of inspiration, rising at the end of expiration to +10° C.

The inference is that in very cold climates slow respiration is undesirable; there does not appear to be any direct effect on the rate of respiration in cold atmospheres, but there is usually to be seen an increased depth.

The core temperature of the body, as in the alveoli, remains remarkably constant in spite of variations in external temperature, and rather shallow breathing, to avoid bringing cold air down the trachea, would seem advisable; the problem cannot be properly investigated in Man, whose air conditioning area in the nose is relatively inefficient. With keen-scented animals, whose maxillo-turbinal system is very elaborate, it appears reasonable to suppose that warming of inspired air is superior to that of Man; experiments to elucidate this point have been carried out and will be reported later in this communication.

RESPONSE OF SKIN TEMPERATURE TO COLD AIR IN THE NOSE

The air reaching the nose was, in many of these experiments, at -40° C. (-40° F.) (72° frost F.), and the reason for shrinkage of the mucosa appears to be related to constriction of skin capillaries, a mechanism designed for the prevention of loss of heat.

This effect is somewhat neutralized by the needs of humidification, the mucosa being in a state of slightly greater congestion with this almost completely dry air than when moderately moist room air is breathed.

To investigate this problem the temperature of the skin was taken by means of a thermocouple attached to a galvanometer; this showed lowering of skin temperature when very cold air reached the nose, the explanation being, no doubt, one of protection.

For example, when a man leaves a warmed hut or even an igloo, he will put on extra fur robes or parkas to avoid chilling; but when first out in very cold air, as at the Arctic, it will be some time before warmth passes out through his fur covering, with chilling of the body. He should not wait for this to happen before constriction of capillaries occurs to conserve heat and it is reasonable to assume that the nasal mucosa, the first part of the body to be affected by cold air, sends a reflex signal leading to constriction of dermal capillaries.

Conversely, immersion of the feet or of an arm in cold water leads to constriction of capillaries in the nasal fossae.

In one experiment to measure skin temperature the readings on the galvanometer were with room air 6.1, cold air 5.3 to 5.6 and hot air (74° C.) 6.3 to 6.4. These figures correspond to skin temperatures of 30° C. with room air, 28.75 with cold and 30.5 with hot air, a noticeable change.

AIR CONDITIONING IN ANIMALS

The elaborate maxillo-turbinal system of carnivora, designed for the saturation of inspired air, might be expected to raise the incoming current to body temperature; this differs from the case of Man, with his inefficient nasal apparatus and with a gradual rise in the temperature of cold inspired air through the nasal, pharyngeal and tracheo-bronchial passages, as studied by many investigators and described elsewhere.

The rabbit has a most intricate maxillo-turbinal body, but is unsuitable for experimentation, and cats also presented difficulties, as the application of a mask to the nose led to an abnormal rise of intra-tracheal pressure; it was necessary, therefore, to use dogs for investigation.

With a mask fitting the snout and with elimination of dead space as far as possible, air was led to the nose from a cooling or a warming system and was expired through a light butterfly valve fitted into the mask; thermocouples were inserted into the nose-piece and also into the trachea and a large bore needle (2 mm.) was placed in the trachea to record pressure.

As might be expected, pressure in the trachea was higher than in Man owing to the considerable obstruction offered by the sieve-like maxillo-turbinal system, varying from 50 to 70 mm. H_2O (Fig. 5). With dry air reaching the nose at -39° C., the temperature in the mask was -2° C. at the end of inspiration, owing to the warming effect of expired air. The temperature in the trachea was raised to +37° C., a rise of over 76° C. above the air supplied, while the animal's body temperature was 37.2° C. (Fig. 18).

As seen in the tracing, intratracheal pressures did not vary much when air at -39° C., +21° C., or +50° C. was used, showing that there was no marked dilatation or constriction of mucosal capillaries and no obvious filling of sinusoids:

C. delivered to nose	*R.H.*	*Tracheal Temp.*	*Pressure in Trachea*
-39° C. (-39° F.)	0	+37 (98.4° F.)	70 mm. H_2O
+21 to 26° C. (69° to 79° F.)	0	+36	50 ,,
+48° C. (120° F.)	0	+36	64 ,,
+20° C. (68° F.)	55%	+37	60 ,,

suggesting that there is some capillary dilatation with very cold air, unlike the case of Man.

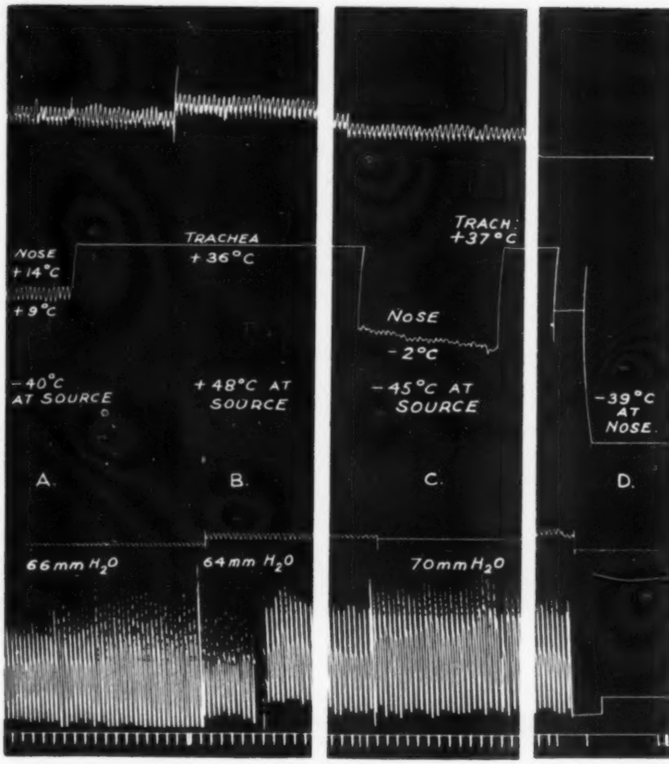


Fig. 18. Response of nose of a dog to varying temperatures. The air in each case was dry and it is seen that the warming of expiratory air brings very cold air to a minimum of +9° C. in the first record (*a*) and to -2° C. (*c*) at the front of the nose; in tracing (*a*) the tracheal temperature was +36° C. and in (*c*) it was +37° C. (*d*) shows that air reached the nose at -39° C. The tracheal temperature when hot air is breathed is +36° C. at (*b*). Pressures in the trachea do not vary much; they were 60 mm. H_2O without the blower, 66 mm. H_2O with blower, in response to very cold air (*a*), 64 mm. with hot air (*b*), and 70 mm. at (*c*) ; this is unlike the recordings in Man.

It would thus appear that the nose of a dog is extremely efficient in bringing the temperature of inspired air up to or down to the temperature of the body.

The greater intra-tracheal pressure suggests increased nasal resistance, but this delaying action may be of benefit, not only for purposes of olfaction and air conditioning, but also for pump action on the circulation.

In another experiment arranged similarly, two thermocouples were fixed in the trachea by means of a curved plastic disc; one couple had a winding of wet cotton to give a differential temperature in order to record humidity; with air at 21.5° C. R.H. 50 per cent. and with air at −40° C. R.H. 0 per cent. the readings of the two thermocouples were almost identical, showing that the air passing through the nose to the trachea was saturated with moisture.

SUMMARY

A certain lack of uniformity in some of the experimental results in Man suggests that the nose is not deeply concerned in the welfare of the lower respiratory tract, but that its efficiency in warming and moistening air is primarily directed to the olfactory sense.

The nose of Man is certainly inefficient, but even if it were designed on a plan similar to that of keen scented mammals yet insufficient protection would be derived because of the human habit of conversing with the mouth open, thus neutralizing the benefits of nasal respiration.

In this respect the higher apes, whose epiglottis is not in permanent contact with the soft palate, also have the faculty of breathing freely through the mouth on occasion; their habitat in hot and humid tropical countries prevents damage to the lungs similar to that experienced by mouth-breathing Man in cold and damp climates.

CONCLUSION

As already stated, the object of this communication is to draw attention to a method of investigation which may lead to useful results.

In this research great benefit has been derived from investigations carried out at the Ferens Institute of the Middlesex Hospital Medical School, particularly in respect of comparative anatomy and physiology: these researches have been continued in the Departments of Anatomy and Physiology at the Royal College of Surgeons of England, where every facility has been afforded by Professor Causey and Professor Slome.

Doctor Wyke also has given advice on various subjects and has assisted in some of the experiments and investigations.

Professor Woolmer and his staff in the Department of Anaesthesia have given valuable assistance in problems of air flow and have acted as subjects for experiment. Dr. Tompsett prepared the mould of the nasal passages from which measurements of available air way were measured, and Mr. Bartlett assisted materially in this direction and in many others.

Mr. Redman has taken many photographs of tracings and anatomical preparations and Mr. Drewell has given expert assistance, particularly in animal experiments.

Finally, to Mr. S. Steward very much is owing for his long continued assistance and for his skill in the design, construction and employment of apparatus; without his help the work would have been impossible.

Professor Slome has co-operated in much of this experimental work, and discussion with him as to procedure and the interpretation of results has been most valuable; he has also been kind enough to read this communication and to suggest some alterations and additions.

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THE USE OF PHYSICAL METHODS OF MEASUREMENT IN ANAESTHETIC RESEARCH

by

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Modern anaesthetic research tends to make use of more and more information, if it is readily available, on the function of the human or animal subject. The availability of this information is due in no small measure to the development of physical methods of measuring parameters in the fields of respiratory physiology and the cardio-vascular system.

Not so long ago, it might have been true to say that the application to anaesthesia of electronic equipment was regarded with some caution by anaesthetists. Today, however, experience shows that, provided the equipment offered will perform the duties required, the anaesthetist will not hesitate to suggest further applications. It must be borne firmly in mind by all concerned that the use of any auxiliary equipment must in no way be allowed to impair the clinical judgment of the anaesthetist or surgeon. When many physiological variables are being recorded it is easy to try to monitor the subject's condition by looking at the meters and not the patient!

Obviously electrical equipment must be utterly reliable when in use in the operating room. The distraction of blowing fuses is hardly to be welcomed by the surgical team. As with running a car, it is necessary to plan a regular system of maintenance. This particularly applies to the routine checking of mains input leads and plugs, since these are liable to get wet and to be pulled by passing trolleys or tripped over by the nurses.

In addition, stress must be laid on the need to allow the apparatus time to attain a steady working temperature. Electronic circuits using thermionic valves dissipate heat causing the interior of the cabinet to " warm up ". After a time a thermal equilibrium is set up with the surroundings and the temperature remains constant. During this warm-up time the calibration of the equipment is liable to significant changes. In order to eliminate the need for frequent re-calibration the equipment should be switched on at least half an hour before it is required for use. This can be a nuisance when it is to be used for the first case on the morning's operating list. For this reason we employ an electric time switch, of the type used to control shop lighting, to switch on the apparatus about an hour before it is needed.

When a patient is anaesthetized he is almost always breathing an artificial atmosphere. Hence it follows that the development of methods of

gas analysis is of considerable importance in anaesthetic research. Physical methods of gas analysis are being used to great advantage and it will be of interest to discuss them in some detail.

The application of physical methods of gas analysis to anaesthesia

Infra-red gas analysers of the Luft type (Luft, 1943) are widely used for the measurement of carbon dioxide, nitrous oxide, ether, halothane, chloroform, trichloroethylene, cyclopropane and water vapour. A schematic diagram illustrating the principle of operation is shown in

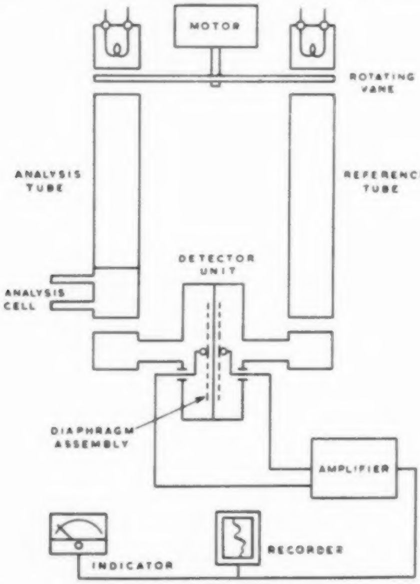


Fig. 1. Schematic diagram of an infra-red gas analyser.

Figure 1. An electrically heated wire spiral emits infra-red radiation which passes along two tubes, one of which contains the analysis cell. The end windows of the cell are made of a material which is transparent to infra-red radiations of wavelengths corresponding to the absorption band of the gas or vapour under investigation. Through this cell a pump draws a steady stream of the gas mixture from the anaesthetic circuit. Finally the two beams of radiation fall one on to each half of the detector unit. This consists of two identical chambers separated by a thin flexible metal diaphragm forming one plate of an electrical condenser. Each half of the detector is filled to a sub-atmospheric pressure with a pure sample of the gas or vapour whose concentration the instrument is to record.

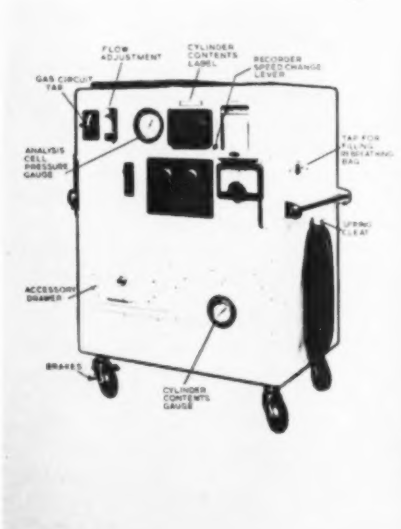
As an example let us consider an infra-red carbon dioxide analyser, the detector unit of which is filled with pure carbon dioxide. The beam of radiation passing through the analysis cell will be called the analysis beam and the other beam the reference beam. With the exception of the analysis cell the optical pathway of each beam is purged with a stream of nitrogen which does not absorb any infra-red radiation. This stream will sweep away any carbon dioxide evolved from the wire spirals. With no carbon dioxide present in the analysis cell it is arranged that the strengths of the two beams falling on the detector are equal. Under these conditions the output meter of the analyser will indicate zero carbon dioxide. Now suppose that the analysis cell contains some carbon dioxide. This carbon dioxide will absorb some of the analysis beam causing it to be weaker than the reference beam when it falls on the detector. When the analysis beam and the reference beams fall on the detector some of their radiation will be adsorbed by the carbon dioxide in the detector and the heating effect will cause the gas to expand. Since the analysis beam is now weaker than the reference beam, the gas on which it falls will not expand as much as that on which the reference beam falls. As a result the metal diaphragm will be pushed towards the analysis beam half of the detector, and this will alter the electrical capacity of the detector unit. This change is amplified electrically and deflects the output meter, which is calibrated in percentage carbon dioxide, typically from 0–12 per cent. v/v.

In a practical instrument the infra-red beams are interrupted some twenty-five times per second by a rotating shutter. The subsequent amplification of the signal from the detector is made easier by having the signal chopped by the shutter. The subtlety of this type of analyser lies in the fact that the detector will respond only to those infra-red wavelengths which it is capable of absorbing. Thus an analyser set up for one gas should not be affected by the presence of another gas unless the absorption bands of the two gases overlap. Any overlapping that occurs is eliminated by the use of a filter cell. In this way the interfering radiation is absorbed before it can fall on the analysis cell. This is a point of practical importance if we consider an infra-red halothane analyser which is to record the halothane concentration of a patient's expirations. If the filter cell is not filled with a suitable mixture of nitrous and carbon dioxide then a false reading of considerable magnitude is obtained when there is no halothane in the anaesthetic mixture.

Ramwell (1957) and Cooper (1957) have shown that the calibration curve of the analyser is dependent on the nature of the diluent gas stream. Our practice is to make up the calibration cylinders of different percentages of carbon dioxide in a mixture of 70 per cent. nitrous oxide and 30 per cent. oxygen. When the analyser is used to monitor the expired carbon dioxide concentration of a patient it is then arranged that the patient breathes a 70 per cent. nitrous oxide-30 per cent. oxygen mixture.

The phenomenon arises from a broadening of the absorption band of the substance being analysed owing to the collisions occurring between its molecules and those of the diluent gas.

A factor which may be important is the response time of the analyser. The volume and shape of the analysis cell will have a great influence on the time lag elapsing between the arrival of the gas sample at the analysis cell and the meter attaining 90 per cent. of its final reading. This is the usual definition adopted for response time. When it is desired to



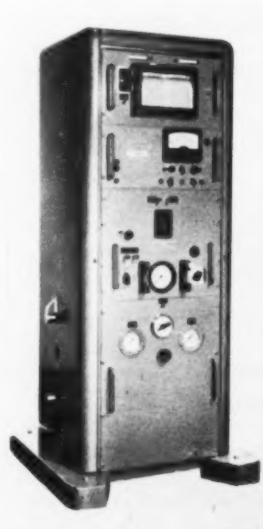


Fig. 2 (*left*). Rapid infra-red carbon dioxide analyser designed for clinical use.

Fig. 3 (*right*). Rapid infra-red halothane analyser with automatic sampling and recording facilities.

trace out the carbon dioxide " plateau " corresponding to each individual breath this time should be a tenth of a second or less. If a carbon dioxide analyser is being used to determine the physiological dead space of a patient, it is necessary to measure accurately the response time of the analyser under the conditions of use of the instrument (Nunn and Hill, 1960). Modern analysers in which the infra-red beams are interrupted some twenty-five times or more per second are satisfactory for single breath working, but older instruments which have an interruption rate of six per second are too slow.

With a well designed instrument a response time of a tenth of a second can be obtained with a sampling flow rate of one hundred millilitres per minute, allowing alveolar carbon dioxide plateaux to be obtained from babies of only a few hours old.

Figure 2 shows an infra-red carbon dioxide analyser designed for clinical use. It is completely self contained with its own sampling pump, calibration cylinder and pen recorder. All the working parts are contained in flame-proof containers which can be purged with nitrogen to eliminate any explosion risk when the apparatus is used in the operating room.

Figure 3 shows an infra-red analyser designed to measure ether or halothane. An automatically operated sampling valve switches the analyser input from the patient's inspiratory gas stream to the expiratory gas stream after a suitable time interval. The apparatus has been specifically designed to investigate the uptake and elimination of anaesthetic vapours by patients.

The paramagnetic oxygen analyser

Of all the gases and vapours encountered in anaesthetic practice oxygen alone is markedly paramagnetic, and because of this fact oxygen molecules are attracted into a magnetic field. The oxygen molecules present in the anaesthetic gas mixture are attracted into the strong magnetic field of a permanent magnet. By displacing some of the gas previously there the oxygen molecules cause a small glass dumb-bell to rotate. The dumb-bell rotates against the torsion of a quartz suspension and takes up an equilibrium position in which the magnetic rotational force is counter-balanced by the torsional restoring force of the fibre. The degree of rotation of the fibre is recorded by means of a light beam moving across a scale calibrated in percentage of oxygen or in partial pressure. For the clinical anaesthetist the great advantages of this instrument are its reasonable price and portability. The few millilitres of gas required as a sample are drawn into the instrument by means of a suction bulb. Its use in anaesthetic practice has been described by Woolmer (1956). The paramagnetic analyser is also of use in checking the oxygen concentration in oxygen tents.

The gas chromatograph

The use of gas chromatography provides a powerful new method for the analysis of multi-component gas and vapour streams. On a single apparatus virtually all the various gases and vapours encountered in anaesthetic practice can be analysed.

Basically, the apparatus comprises one or more columns through which flows a steady stream of a carrier gas which may be hydrogen, helium or argon. The columns are composed of a glass or metal tube packed with

an inert supporting substance, such as firebrick, which is impregnated with a low vapour pressure organic liquid, such as dinonyl phthalate. The columns may have a length ranging from some two feet to twenty feet or more depending on the nature of the components to be analysed. The longer columns are wound in the form of spiral coils for compactness.

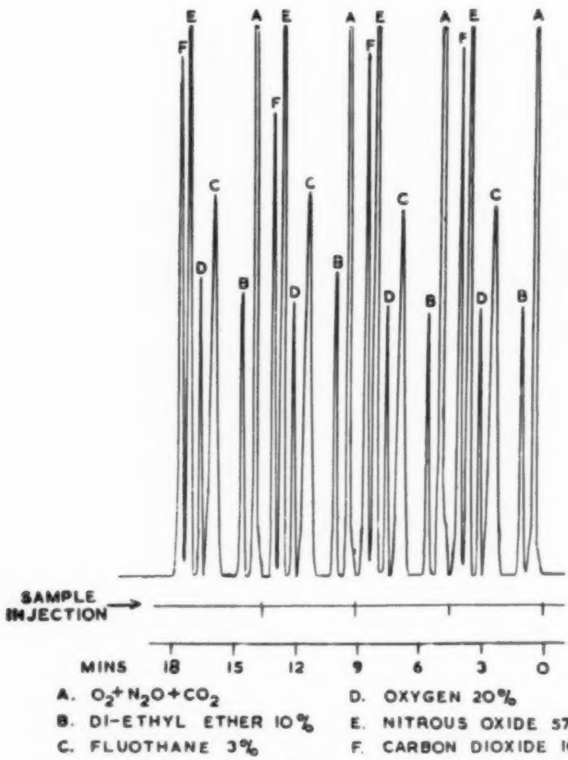


Fig. 4. Routine monitoring by gas chromatography of the output of a Boyle anaesthetic machine.

A few millilitres of the gas stream to be analysed are inserted into the carrier gas stream at the beginning of the column. The individual components of the sample mixture will travel through the column at different speeds, depending on their affinity for the column packing. Thus the components emerge from the end of the column at different times. The problem now is to detect their emergence.

The most usual method is to detect the change in thermal conductivity between the carrier gas alone and the carrier gas plus each sample component. The change in thermal conductivity of the gas stream is converted into an electrical voltage and fed to a pen recorder. For each component emerging from the column the recorder traces out a peak on the chart. With the operating conditions of the gas chromatograph held constant a calibration curve may be obtained between the peak height and the concentration of the component. The time elapsing between the injection of the sample and the emergence of the appropriate peak identifies the component in question.

The great attraction of gas chromatography lies in its versatility since it can handle oxygen, nitrogen, carbon dioxide, ether, halothane, cyclopropane, chloroform and trichloroethylene. For this reason it should be a useful method for monitoring concentrations in anaesthetic circuits, checking vaporisers and demonstrating to students.

In contrast to infra-red analysers which are continuous in action, the gas chromatograph needs to be fed with a series of samples and is therefore not rapid enough in response to follow individual breaths. For most purposes, however, this is no serious drawback.

The samples are injected automatically by means of an electrically operated sampling valve at pre-set intervals. Figure 4 shows the chart record of the gas chromatograph sampling the output from a Boyle anaesthetic machine, with samples being taken every four and a half minutes. In order to allow all the peaks to be seen on the chart the lower concentration components, ether, halothane and carbon dioxide, are recorded at a higher gain setting than are oxygen and nitrous oxide. The gas chromatograph represents a practical possibility of applying the principles of automation to anaesthetic gas analysis.

The routine calibration of gas and vapour analysers

The provision of an easy means of calibrating gas and vapour analysers in the operating room, as distinct from the laboratory, requires care. Our practice is to make up cylinders containing known percentages of gases and vapours. Rusty cylinder walls can certainly absorb halothane and therefore only alloy cylinders or steel cylinders which have been tin lined should be used. The contents of the cylinder must also be thoroughly mixed, otherwise the concentration of the components drawn from the cylinder will vary with the amount of gas contained in the cylinder.

Blood gas studies

An instrument which is rapidly gaining in popularity is the oxygen polarograph (Severinghaus and Bradley, 1958). With its aid oxygen

tensions in blood and biological fluids can be determined and also concentrations of oxygen in gas mixtures. The range from zero up to 100 per cent. can be covered.

The use of polarographic techniques with whole blood has been greatly extended with the development of the Clark electrode (Clark, 1956), and this type of electrode is used in the polarograph of Severinghaus and Bradley. The electrode is a small cell having a platinum cathode and a silver anode. The electrodes are immersed in a saturated potassium chloride solution. In order to eliminate effects arising from the red cells in the blood, Clark separated the blood from the platinum cathode by means of a thin oxygen permeable membrane such as cellophane or Teflon. With a steady potential difference applied of 0.6 volt the current drawn from the cell is proportional to the oxygen tension in the blood. It is necessary to stir the blood during the measuring procedure and this is accomplished with a magnetic stirrer. The currents are of the order of one micro-amp and can be measured with a sensitive galvanometer or by a vibrating reed electrometer. The calibration of the polarographic cell is temperature dependent and therefore in use the cell is surrounded by a circulating water bath at body temperature.

Severinghaus and Bradley also describe another electrode assembly for measuring the tension of carbon dioxide in arterial blood. It consists of a dome-ended pH electrode covered with a Teflon membrane. A layer of sodium bicarbonate solution is trapped between the electrode and the Teflon membrane which is in contact with the blood to be measured. Carbon dioxide from the arterial blood sample diffuses through the membrane and alters the pH of the bicarbonate solution. The electrode is calibrated against standard gas mixtures containing known percentages of carbon dioxide. In this way the changes of pH can be related to the carbon dioxide tension in the blood.

Apart from gas and vapour analysis there are many other applications for physical principles in anaesthetic research and some of these will now be described.

The use of pressure transducers

For many purposes it is necessary to be able to record pressures, as, for example, airway and oesophageal pressures and venous and arterial blood pressures. The range to be covered extends from a few millimetres of water to several hundred millimetres of mercury. In order to accomplish this, some sort of transducer is necessary to convert the pressure into an electrical signal. The types most commonly encountered are based on a capacitive or on an inductive principle. The basic mode of operation is the conversion of a small change in the geometry of the transducer into a large change of some electrical quantity.

In a capacitance manometer the pressure to be measured is applied to a flexible metal diaphragm forming one plate of an electrical condenser. The resulting capacity changes give rise to voltage changes which are then amplified and displayed on a pen recorder or cathode ray tube.

The differential inductance transducer consists basically of an iron core wound with a primary winding and two identical secondary windings. The secondaries are wound in series opposition. The pressure to be measured is applied to a flexible diaphragm which carries an iron armature. When the applied pressure is zero it is arranged that the electro-magnetic coupling between the primary and each of the secondaries is equal and opposite. Thus, when the primary is energized with an alternating current of some 2,500 cycles per second, there will be no resultant output from the combined secondary windings. Movement of the diaphragm will increase the coupling between the primary and one secondary, and decrease it between the primary and the other secondary. In a well designed transformer the voltage output will be proportional to the applied pressure. A differential transformer transducer will generally cover a wider range than a capacitance transducer, but will not be quite as sensitive as the most sensitive capacitance transducer.

Another form of transducer in common use is the American R.C.A. transducer valve type 5734. This consists of a small triode valve which has a movable anode. The valve is arranged in a simple bridge circuit with its anode attached to a diaphragm to which is applied the pressure to be measured. Movements of the diaphragm which are proportional to pressure changes are transmitted to the anode, causing the bridge circuit to unbalance and a meter or recorder to deflect. An interesting use of this device occurred when it became necessary to monitor the respirations of an anaesthetized pig undergoing neutron irradiation from a cyclotron. Because of possible radiation hazards thick concrete walls surrounded the cyclotron, and in fact the anaesthetic gases and electrical connections had to pass through eighty feet of pipe. The pig could be observed with a telescope through a water-filled window, but not sufficiently well to control the level of anaesthesia. Thus a short length of corrugated anaesthetic tubing closed at both ends was tied with the aid of webbing around the pig's chest. Respiratory movements produced pressure changes in the tubing which were measured with the R.C.A. valve transducer. The valve was adjacent to the pig, but the control unit and recorder were outside the cyclotron chamber. A nitrous oxide-oxygen mixture supplemented with halothane was employed as the anaesthetic, the halothane concentration being adjusted to maintain an even respiratory tracing. On two occasions the trace rapidly diminished and these were traced to a kinked endotracheal tube and to the emptying of the oxygen cylinder. Fortunately, it is not every day that the anaesthetist has to be eighty feet away from his patient.

In respiratory studies, as well as measuring pressure it is usually necessary to record the patient's ventilation. This is usually carried out with the aid of some form of spirometer. However, the use of an integrating pneumotachograph offers advantages, particularly when one is recording several parameters on the same chart paper.

The pneumotachograph is a device for recording flow rates. A resistance to flow, often a gauze, designed so that the pressure drop produced across it is linearly proportional to the flow rate of gas through the resistance is placed in the airway. A sensitive capacitance manometer measures the pressure drop of the order of a few millimetres of water and

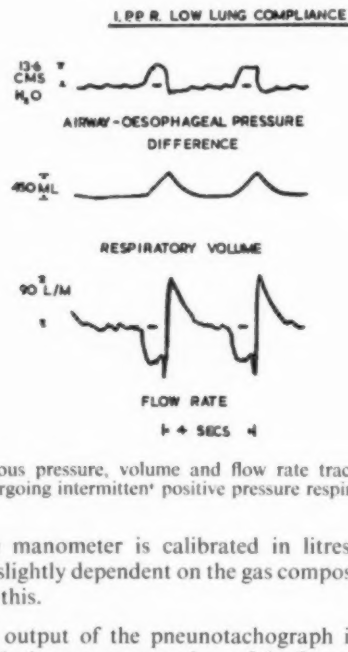


Fig. 5. Simultaneous pressure, volume and flow rate tracings from a patient undergoing intermitten' positive pressure respiration.

the output of the manometer is calibrated in litres per minute. The calibration will be slightly dependent on the gas composition and allowance must be made for this.

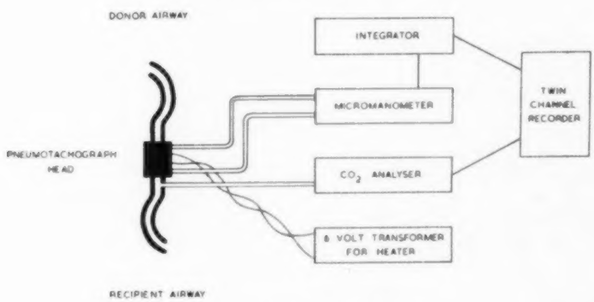
If the electrical output of the pneunotachograph is fed into a device which will add up the instantaneous values of the flow rate over a breathing cycle then the output of this device, which is called an integrator, will be in terms of tidal volume.

Physiological parameters are generally recorded on a high speed pen recorder. Although recording on photographic paper or film is often used to obtain a better definition, recording with a pen on paper is convenient for routine use. The cost of the paper is insignificant with ink writing pens, but is rather expensive when hot stylus pens are employed.

However, the latter system eliminates troubles arising from ink blots. In the Research Department of Anaesthetics the main recording equipment is a six-channel Sanborn physiological recorder. The pens will respond at frequencies up to some eighty cycles per second and suitable pre-amplifiers are available to measure blood pressures, the electro-cardiogram and the output of gas analysers. The recorder employs a hot stylus writing system.

Generally speaking, a recording channel consists of a transducer, appropriate pre-amplifier, power amplifier and a pen recorder. The power amplifiers driving the pens are the same for each channel. Each channel should be calibrated with the fundamental quantity it is intended to measure.

EXPIRED AIR RESUSCITATION



RECORDING EQUIPMENT

Fig. 6. Flow diagram for experiments on expired air resuscitation.

For example, the integrating pneumotachograph would be calibrated with known volumes from a large syringe, the plunger being actuated at normal respiratory rates.

A typical mechanics of breathing trace is shown in Figure 5. The top trace shows the airway-oesophageal pressure difference measured with a differential inductance manometer. Cardiac pulsations are clearly visible. The middle trace shows the tidal volume measured with an integrating pneumotachograph. The bottom trace shows the flow rate curve recorded with a capacitance manometer across the pneumotachograph head. The patient was undergoing intermittent positive pressure respiration and had a low lung compliance. Expiration was almost passive. If desired, the pressure and volume traces may be displayed as pressure-volume loops on a cathode ray tube. This form of display is very effective in showing the effect of any increased resistance to breathing present in breathing circuit components.

With the aid of a servo-multiplier it is possible to multiply together the instantaneous values of pressure and volume throughout the respiratory cycle and obtain an output in terms of the work expenditure in moving the gas around the circuit. Or by multiplying the instantaneous values of pressure and flow rate one obtains a result in terms of the power or rate of doing work per breathing cycle. Rather a far cry from the mechanics one learnt at school!

The integrating pneumotachograph has proved particularly useful in assessing the merits of mouth to mouth resuscitation. In practice airway to airway resuscitation was employed with the pneumotachograph head inserted between the two airways, where it does not interfere with the task of the donor. A flow diagram for the method of investigation is shown in Figure 6 and a typical tracing in Figure 7. In addition to the tidal volume of the subject, the expiratory carbon dioxide levels of the subject

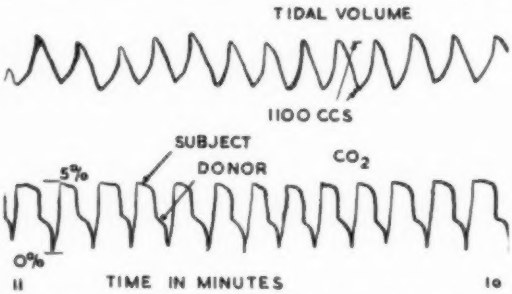


Fig. 7. Airway to airway resuscitation. Top trace: Tidal volume recorded by an integrating pneumotachograph. Bottom trace: Expiratory carbon dioxide levels of the subject and donor recorded by a rapid infra-red analyser.

and donor were recorded as an index of ventilation. The lower trace shows that the end expiratory carbon dioxide level of the subject was 5 per cent. v/v and that of the donor 2.4 per cent. v/v after ten minutes of resuscitation. Resuscitation was continued for a total of forty-five minutes in this case.

Following the discovery in this department that dogs can breathe spontaneously for considerable periods carbon dioxide concentrations of 70 per cent. (Graham, Hill and Nunn, 1959), investigations have been carried out to try and ascertain the mechanism whereby the dog adapts itself to these conditions. In this type of work a good deal of measuring equipment is used and the flow diagram for a typical experiment is shown in Figure 8 and a view of the equipment in Figure 9. It was particularly necessary to have warning of any cardiac arrhythmias and to this end a cardioscope was used for continuous visual monitoring of the electrocardiogram. In addition aural warning was given from a cardiophone.

This device is basically a thousand cycle per second tone generator whose amplitude is modulated by the E.C.G. signal applied to the plates of the oscilloscope. It forms a cheap and most useful accessory. The electrocardiogram is also fed into a simple ratemeter scaled 0–250 beats per minute. The rectal temperature is indicated by an electrical resistance thermometer which utilizes a large circular scale indicator. This instrument is an adaptation of a standard boiler house instrument, and is particularly valuable in hypothermia experiments. The large clear dial is an attractive feature.

When several people are recording observations simultaneously it is vital that they all work to the same time scale, so that events noted on more than one recorder chart can be synchronized at the end of the experiment. When a conventional laboratory stop clock is used, difficulty is often

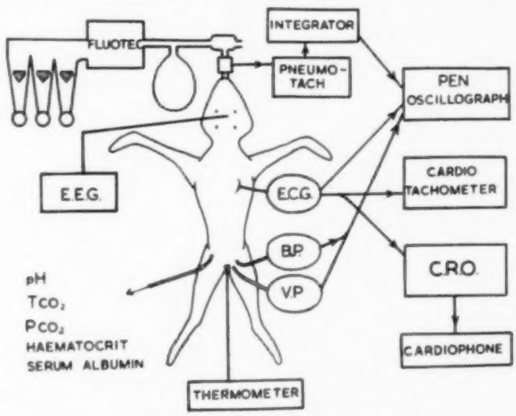


Fig. 8. Flow diagram for " supercarbia " experiments.

experienced in reading the hands at a distance. Thus in these experiments we employ a clock with a digital read-out in minutes and tenths of a minute so that there will be no reading error. Subsidiary slave clocks can be driven from the master unit to cater for individual workers.

As part of the basic equipment of an anaesthetics research laboratory the instruments described also find regular use in the routine testing and evaluation of respirators and anaesthetic equipment. Practical demonstrations are also provided for students at the College studying for the Fellowship in the Faculty of Anaesthetists. A recent development has been the running of a week's full-time course on instrumentation for cardio-respiratory research. Each afternoon is devoted to experimental work so that the students can become familiar with the best modern equipment.

Fig. 9. Equipment used in " supercarbia " experiments.

It is hoped that this article will have achieved its aim of showing how recent advances in other disciplines such as physics and electrical engineering may be of service.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the encouragement of Professor Ronald Woolmer in this work. Also all those members of the staff of the Research Department of Anaesthetics who have applied the techniques described to clinical studies. Figures 5 and 7 are reproduced with the permission of the editor of the *British Journal of Anaesthesia* and Figure 6 by permission of the editor of the *Lancet*.

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REBUILDING OF THE COLLEGE: PROGRESS REPORT

AT THE CEREMONY on 29th March 1960, marking the conclusion of the penultimate phase of rebuilding in the College, the Chairman of the Building Committee described the final phase on which work was about to start as " the beginning of the end ". It is this thought which sustains the morale of all who work in or visit the building at the present time during a period of considerable inconvenience while demolition and the first stages of the final building are in progress.

Demolition has left the College building with a much scarred façade at the north-west corner. Much of the external wall on the west side of the portico is seen to be an empty shell, and at its west end (Fig. 1) it finishes in a jagged edge of brickwork, supported by a wooden shore. There is a projection at third floor level resting on girders and on a reinforced wall in

Fig. 1. The west end of the College.

a manner which gives little confidence to the lay observer, who will also be puzzled by the radiator, still connected to the central heating system, which has been exposed to all weathers since March. In addition there is evidence of demolition at roof level, where the mansard roof behind the sixth floor parapet has been removed (Fig. 2). Inside the College, most of the Inner Hall has been walled off, as has been part of the first floor landing, where the demolition of part of the west wing of the old College building has been in progress (Fig. 3). Of new building, all that can at present be seen is the work to the concrete foundations and ground floor supports on the west side of the site, adjoining that of the Imperial Cancer Research Fund (Fig. 4).

Fig. 2. The sixth floor roof.

It is hoped to publish progress reports in the *Annals* from time to time, but a brief summary of the intentions of the last phase may be welcomed now. Those familiar with the old west side of the building will recall that, with the exception of the Library, the main rooms, notably Museums I and III and the Council Room, were aligned on a north-south axis from Lincoln's Inn Fields. The main feature of the new plan is the re-orientation of the chief rooms, now to be the new Lecture Room I and the Hunterian Museum, to run from east to west. The former will occupy the area to the west of the Inner Hall, and there will also be a small Lecture Room to the west of the old Museum Hall, which has already been converted into administrative offices.

The Hunterian Museum, entered from the centre of the first floor landing, will form a galleried hall, two storeys high, on the site of the old Council Room and upper part of the old Museums III and I. There will also be a Rare Book Room to the west of the Librarian's Office. The Museum will have a curved glass roof which will form the floor of a well, bounded on the west side by the four floors of the new laboratory build-

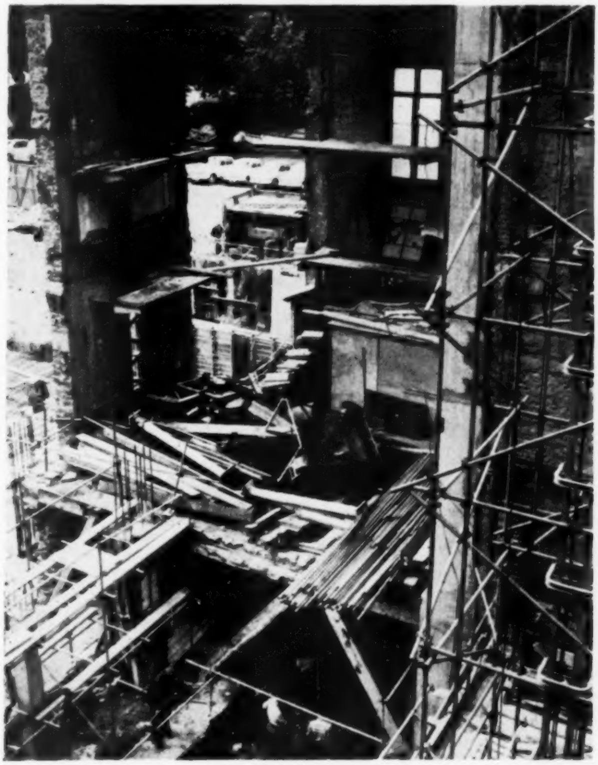


Fig. 3. Another view of the demolition of the west end of the College.

ings (known to the Building Committee as " Phase IIIb ") which will link the old College building to the most recent laboratories on the Portugal Street side.

The third floor of this new laboratory wing will house the offices of the Joint Secretariat, the fourth, fifth, and sixth providing new laboratories for adjacent departments. The fourth storey will form part of the Department of Anatomy, connecting with the rest of the Department in the

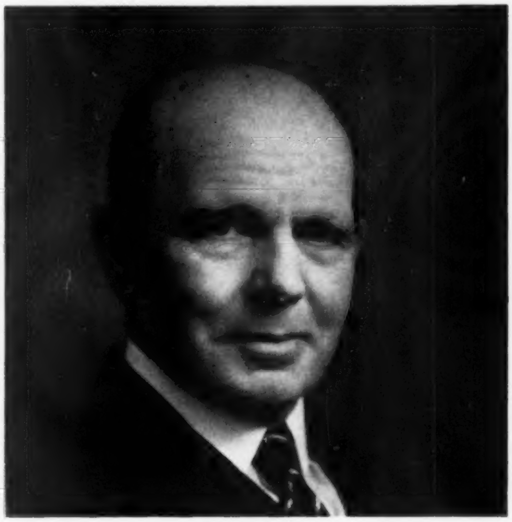
Portugal Street wing. The new Department of Biochemistry will occupy the adjacent fourth floor of the old College Building. The Departments of Physiology and Pharmacology will occupy the fifth and sixth floors of the old College Building and the fifth and sixth storeys of the new laboratories.

Fig. 4. Demolition at the west end of the inner hall.

These changes require some modification of the upper floors of the old College building; of these, the fourth (with circular windows) and the fifth are those added to Sir Charles Barry's building in 1890 by Stephen Salter. These were last subject to alteration in 1937, when they were converted to Research Laboratories by the generosity of the Bernhard Baron Trustees: the mansard roof of the sixth floor, which dates from this conversion, is now being remodelled to improve the shape of rooms on the north side.

In Memoriam

SEYMOUR GILBERT BARLING, C.M.G., M.S., Ch.M., F.R.C.S.



Seymour Barling

THE PASSING OF Seymour Gilbert Barling on the 4th July last will bring back to those who were fortunate enough to have been his students, trainees or colleagues, memories of kindly friendship and sound advice. Somewhat short of stature he had a fine head and great dignity of personality. Indeed, he was typical of the relatively quiet times and gracious age of pre-Second World War days. He came of farming stock and loved country life, its skills and pursuits to the end of his days.

He joined the Birmingham Medical School in 1898 and qualified in 1903. He then held various junior hospital posts, including one at Great Ormond Street, and was appointed to the Staff of the General Hospital in 1910. These were times of great change. His own teachers had been jacks-of-all trades, who worked with the simplest of equipment in hospitals dependent on charity, sometimes having to close wards because of shortage of funds. His uncle, the late Sir Gilbert Barling, was one of the first surgeons in Birmingham to have the newer scientific outlook, and there is no doubt that Seymour Barling came greatly under his influence; he was his assistant for some years. These were the days when the assistant Staff were truly

" assistants ", and one of Seymour's particular interests, once he became a Senior, was to improve the lot of the young members of Staff, getting his senior colleagues to agree to a more generous allotment of beds and encouraging young men to travel to other Centres in order to enlarge their experience and outlook.

He was a keen Territorial, and was called up as soon as World War I opened, and served throughout. One heard that he was an excellent Commanding Officer, and he finished by becoming one of the Consultant Surgeons to the B.E.F. His work is mentioned on a number of occasions in the Official History of the Medical Services during that conflict, and he was awarded the C.M.G. for his services.

He returned to Birmingham as a Senior Surgeon to the General and the Children's Hospitals and threw himself into the interests of civilian surgery and the teaching of medical students. He played an increasingly prominent part in Hospital and Medical School affairs, yet he always insisted on a well-balanced life; his operating lists rarely exceeded 3-4 hours, he always left hospital after rounds by 12.30 p.m., and his week-ends were sacrosanct. He was profoundly conscientious regarding his patients, and his chief interests were in gastric and thyroid surgery and in the surgery of infancy. Like others in the early twenties, he was a general surgeon in its widest meaning, the newer specialities not yet being established, though a modicum of specialization was developing and he saw that this was essential for progress. He was always prepared to face change, whether it was in hospital administration, teaching methods or the improved status of the younger men, and he did not shrink from breaking with tradition as, for instance, the rigid correspondence, for consultative purposes, between physician and surgeon just because they happened to be of equivalent seniority; or, once various workmen's hospital fund organizations had become established, the admission to membership of the Board of Governors of a trades union man.

It was during this time that there seemed need for expansion at both the teaching hospitals, and beginnings were set going; indeed, building actually started at the old Queen's Hospital. And then a group of eminent citizens suggested that something really new should be considered, namely that a new hospital, together with a new Medical School, should be built adjacent to the University with the aim that proximity to its various departments would encourage research into clinical problems and, as a result of easy conference with experts in the fundamental Sciences, make it more worthwhile and fruitful. In other words, the Medical School with its Hospital would become an integral part of a University with all that that means. The Cadbury family gave land in contiguity with the University territory so that to all intents and purposes the Medical School and Queen Elizabeth Hospital are on its campus. Seymour Barling was a leading light in all the effort needed for putting such a novel idea into being. It was not achieved

without difficulty, and one gesture he made—indeed, a major contribution—was to sacrifice his seniority in order to make smoother the integration of the Staffs of the two Teaching Hospitals.

He became Professor of Surgery in the University of Birmingham in 1928 and a member of Council of the Royal College of Surgeons of England in 1935. He was also a member of the Court of Examiners of the Royal College of Surgeons. These two latter appointments gave him especial pleasure, for he was a great man for friendships and regarded his College contacts as of his happiest. His publications were numerous, probably the best known being *A Manual of War Surgery* together with John T. Morrison; numerous articles on thyroid surgery and the surgery of hypertrophic pyloric stenosis in infancy; and *Diseases of Infancy and Childhood* with his life-long friend, Leonard Parsons, which went into two editions. In 1934 he became President of the Association of Surgeons of Great Britain and Ireland when it met in Birmingham, and he was a most enthusiastic member of the Moynihan Chirurgical Club. It is perhaps characteristic of his love of his friends that he attended the fiftieth anniversary of the latter, when it was celebrated in Leeds only last autumn, and also the Annual Dinner of the Association of Surgeons when it met in Birmingham in April of this year. Both occasions gave to him the greatest pleasure and to his friends real delight. It is difficult to think that within three months he would be with us no more.

Though prominent in the scenes of his day he was determined to make way for the younger men once his time for retirement came. This he did not find difficult, for his country interests awaited him. Nevertheless, there was still work to do and he played a most useful and energetic part in the organization of the conversion of a hutted war-time hospital near Malvern to one for tuberculosis with a full surgical unit. Once this was established he withdrew to his beloved country. He acquired a small tree-farm, and " looking after trees " gave him especial satisfaction.

His family life was a most happy one. He leaves a widow, a daughter and two sons, both of whom are in the medical profession.

F. A. R. S.

INTERNATIONAL FEDERATION OF SURGICAL COLLEGES

A MEETING OF the above Federation is to be held in London, at the Royal College of Surgeons of England, from the 18th to the 20th October 1960. The theme of the Meeting will be The Training of Surgeons, and the programme will include Lectures, research communications and discussions. Will anyone who is interested in attending all or part of this meeting please write to the Secretary, Royal College of Surgeons of England, Lincoln's Inn Fields, London, W.C.2, for further particulars and enrolment forms.

THE INTERNATIONAL ACADEMY OF PATHOLOGY

THE INTERNATIONAL ACADEMY OF PATHOLOGY, founded in 1906 as the International Association of Medical Museums, held its Third International meeting at the Royal College of Surgeons on 20th–24th June 1960, under the presidency of Dr. F. W. Wigglesworth, of Montreal.

The meeting was officially opened by the President of the College, Sir James Paterson Ross, Bt., K.C.V.O., M.S., P.R.C.S., who read a message from H.R.H. Prince Philip. The meeting attracted a large audience, there being 320 registrants, including over 100 from America, and in

Mrs. Wigglesworth, Dr. F. W. Wigglesworth, Lady Paterson Ross and Sir James Paterson Ross, Bt., who received the guests at the dinner during the meeting of the International Academy of Pathology.

addition to a large number of papers on varied subjects there were special sessions given by invited speakers. The subjects dealt with included the pathology of the kidney, total body radiation, breast cancer and allied lesions, thyroiditis and thyroid cancer.

A full social programme was available for wives and included a special civic reception at Winchester.

The dinner was attended by 258 persons, the College being represented by the President and the Dean of the Institute of Basic Sciences, and the University of London by the Vice-Chancellor.

PROCEEDINGS OF THE COUNCIL IN JULY

An Ordinary Meeting of the Council was held on Thursday, 28th July 1960, with Sir Arthur Porritt, President, in the Chair.

Mr. N. R. Barrett (St. Thomas's) and Mr. W. M. Capper (Bristol) were re-elected Members of the Court of Examiners for a further period of three years, and newly elected to the Court were Mr. C. A. Keogh (The London) (to examine in Otolaryngology), Mr. C. J. B. Murray (Middlesex) and Mr. A. H. Hunt (St. Bartholomew's). Mr. Murray and Mr. Hunt were admitted to the meeting to make the required Declaration on admission to the Court, as also was Professor A. K. Basu of Calcutta, who had been elected some months previously as an additional examiner for two years.

Dr. R. Bryce-Smith (Oxford) was formerly admitted as a member of the Board of Examiners for the Fellowship in the Faculty of Anaesthetists.

The Hallett Prize was presented to Dr. G. V. Shead of Sydney, now working at St. Bartholomew's Hospital and resident in the Nuffield College.

The Council agreed to a request to hold a Primary Fellowship Examination in Pakistan in 1962, provided that the Government of that country can guarantee an adequate number of candidates.

Arising from the Report of the Board of Faculty of Dental Surgery, the Council noted with pleasure the re-election of Professor M. A. Rushton as Dean, the election of Mr. G. H. Leatherman as Vice-Dean, and the re-election of Professors G. L. Roberts and H. H. Stones and election of Mr. W. B. Southwell to the Board of Faculty. Dr. Hamilton B. G. Robinson of Kansas City was appointed Webb-Johnson Lecturer for 1958–61, and Dr. A. R. Ten Cate was appointed Leverhulme Fellow in Dental Research to work in the College's Department of Dental Science.

Among other staff changes were the appointment of Dr. J. Bowes as Geigy Research Fellow in the Department of Anaesthetics, and the resignation of Dr. C. J. Stratman, Research Assistant in the B.E.C.C. Unit of the Anatomy Department. Professor Causey was asked to give an Arnott Demonstration in place of Dr. Stratman.

The Council received most gratefully a further gift of one thousand guineas from Mr. McNeill Love, former member of the Council and Court of Examiners.

The President reported the progress of the College Appeal and mentioned in particular covenants for £25,000 each from Mr. Fred Davidson and Miss Clarica Davidson.

The Council authorized extensive repairs to the Buckston Browne Farm. It is also hoped to make improvements to the Farm, and a Committee has been set up to review possible developments in the College's properties at Downe.

Diplomas were granted to 126 new Members of the College and the Handcock Prize was awarded to Sonia G. Bolton of King's College Hospital.

A Diploma in Orthodontics was granted to one candidate and, jointly with the Royal College of Physicians, specialist postgraduate diplomas were granted in Anaesthetics (94), Laryngology and Otology (25), Industrial Health (8), Pathology (5), Psychological Medicine (72), Public Health (18) and Tropical Medicine and Hygiene (4).

The following hospital posts were recognized under paragraph 23 of the Fellowship Regulations:

Hospitals	Posts Recognized		
	General (6 months unless otherwise stated)	Casualty (all 6 months)	Unspecified
Wigan — Leigh Infirmary (additional)	Registrar S.H.O. H.S. (pre-registration)		
Ipswich — Ipswich and East Suffolk Hospital (additional)			*Under para.* 23 (*b*) Ophthalmic Registrar (12 months)
Epping — St. Margaret's Hospital (additional)		2nd S.H.O. (Orth. & Cas.)	
London — St. Leonard's Hospital (redesignation)	*Redesignation* H.S. redesignated as S.H.O.		
Ryde — Royal Isle of Wight County Hospital (additional)	Surg. Reg.		
Smethwick — Midland Centre for Neurosurgery (additional)			S.H.O. (6 months)
Preston — Royal Infirmary (additional)			2nd Neurosurgical S.H.O.

THE ANATOMICAL MUSEUM

THE SPECIAL DISPLAY for the month of September consists of relics of a Naval Surgeon (Garden Milne, 1791–1852). These will be the subject of an article to be published in the *Annals* in the near future.

THE BUCKSTON BROWNE DINNER 1960

THE DINNER FOR Fellows and Members endowed by Sir Buckston Browne in 1927 was held on 13th July of this year with the President, Sir James Paterson Ross, Bt., in the Chair.

Those present numbered 205, and among the guests were H.H. The Aga Khan, the High Commissioners for Australia and Ceylon, the Minister of State for Foreign Affairs, the Under Secretary of State for the Colonies, Lord Kindersley, Lord Moran, Lord Evans, Lord Cohen, the Vice-Chancellor and Principal of the University of London, the Presidents of the Royal College of Surgeons of Edinburgh, the Royal College of Surgeons in Ireland, the Royal Faculty of Physicians and Surgeons of Glasgow, the Medical Society of London, the Hunterian Society and the College of General Practitioners, the Treasurers of Lincoln's Inn and the Middle Temple, and many other distinguished visitors.

After dinner, when the loyal toasts had been observed and the memory of the donor honoured in silence, the health of the College was proposed by the Rt. Hon. Julian Amery, M.P., Parliamentary Under Secretary of State for the Colonies.

In reply the President, after thanking Mr. Amery for his speech, paid tribute to Sir Buckston Browne, an industrious and enterprising surgeon, an outstanding benefactor of the College, and an enthusiast for John Hunter and Charles Darwin. Sir Buckston had endowed this dinner to promote friendship between the Fellows and Members of the College and to give an opportunity of entertaining distinguished guests. The President mentioned other influences of good fellowship in the College—the *Annals* and its contacts with Fellows all over the world; the monthly dinners; the provincial meetings; and many visits to the College by Fellows whose last visit was on the day of passing their final examination and who, when coming again, were interested and delighted in the work going on in the College today. The College was growing both internally and externally, was receiving appeals for help from overseas and playing a prominent part in such affairs through the Sir Arthur Sims Commonwealth Travelling Professorship and the International Federation of Surgical Colleges. The Faculties of Dental Surgery and Anaesthetists and the Institute of Basic Medical Sciences were all becoming more intimately a part of the College itself as they gained in maturity, and at the same time the responsibilities of the Council were continually growing. The President thanked for their loyal support the Council, the College Staff, and the many enthusiastic laymen who were now identifying themselves with the welfare of the College.

The toast of the Guests was proposed by Mr. A. Dickson Wright, Senior Vice-President, in a characteristically witty speech.

The response was by Mr. Harold Christie, Q.C., Treasurer of Lincoln's Inn, who thanked Mr. Dickson Wright for his remarks and the College for its hospitality. He hailed the common aim of all professional men to uphold professional status and standards, and felt that the Law and Medicine in particular stood side by side in striving for honourable standards. As one who had spent much of his life in Downe, he was especially glad to take part in an occasion at which Darwin and Hunter were honoured, and he concluded by wishing the College all prosperity and success.

DIARY FOR SEPTEMBER

Wed.	21		D.Orth. Examination begins.
Thur.	22		First Membership Examination begins.
Fri.	23	5.00	Board of Faculty of Dental Surgery.
Mon.	26		Surgical Lectures and Clinical Conferences begin.
		5.15	MR. T. T. STAMM—Fractures of long bones.
Tues.	27		Final Membership Examination begins.
		5.15	MR. A. W. BADENOCH—Obstruction of the lower urinary tract.
		6.30	MR. ASHTON MILLER—Treatment of the ureter damaged by surgery or irradiation.
Wed.	28	5.15	MR. R. C. F. CATTERALL—Lesions on the feet of diabetics.
		6.30	MR. ROBERT COX, M.B.E.—The management of malignant ascites.
Thur.	29	5.15	DR. F. S. COOKSEY, O.B.E.—Rehabilitation and resettlement.
		6.30	MR. R. H. FRANKLIN—Reflux oesophagitis.
Fri.	30	5.15	PROF. W. M. DAVIDSON—The anaemias of surgical interest.
		6.30	MR. A. H. HUNT—Surgical treatment in cirrhosis of the liver.

DIARY FOR OCTOBER

Mon.	3	5.15	MR. A. G. PARKS—Surgical management of ulcerative colitis.
Tues.	4	5.15	MR. R. W. REID—Treatment of genito-urinary tuberculosis.
		6.30	PROF. A. J. HARDING RAINS—Gallstones.
Wed.	5	5.15	MR. H. T. SIMMONS—Carcinoma of the tongue.
		6.30	MR. H. J. SEDDON, C.M.G.—Poliomyelitis.
Fri.	7	5.15	MR. A. LAWRENCE ABEL—Carcinoma of the breast.
		6.30	MR. G. W. TAYLOR—The management of occlusive arterial disease.
Tues.	11	5.15	MR. FRANCIS SILVA—Potts paraplegia.
		6.30	MR. J. G. YATES-BELL—Carcinoma of the bladder.
Wed.	12	5.15	SIR RUSSELL BROCK—The scope of open heart surgery.
		6.30	PROF. DIGBY CHAMBERLAIN—Carcinoma of the stomach.
Thur.	13	2.00	Quarterly Council.
		5.00	PROF. C. E. DREW, M.V.O.—Hunterian Lecture—Profound hypothermia in cardiac surgery.
		5.15	MR. T. HOLMES SELLORS—Perfusion techniques in open heart surgery.
		6.30	PROF. C. A. WELLS—Adrenal tumours and related conditions.
Fri.	14	5.15	MR. ERIC SAMUEL—Newer X-ray aspects of acute abdominal emergencies.
		6.30	MR. VICTOR RIDDELL—The surgery of the thyroid.
Wed.	19		Meetings of International Federation of Surgical Colleges.
		5.00	Board of Faculty of Anaesthetists.
Thur.	20		Meeting of International Federation of Surgical Colleges.
		5.00	PROFESSOR J. F. NUBOER—Moynihan Lecture.
Thur.	27		Thomas Vicary Commemoration.
		5.00	DR. CUTHBERT E. DUKES—Thomas Vicary Lecture—Genetics in relation to surgery: a historical review.

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